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SIMULATION OF FIRE IN A VIRTUAL ENVIRONMENT PHASE I: FIREFIGHTER SENSORY DATA

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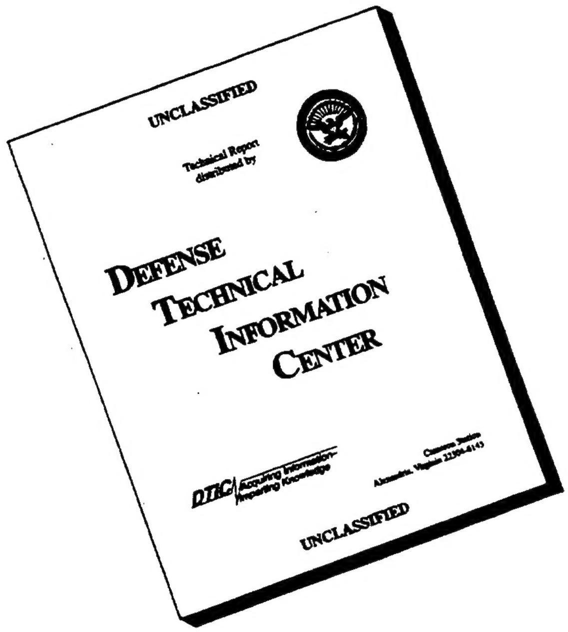

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ABSTRACT

Four Class A structural live fire tests fought by firefighters instrumented for temperature, sound and sight were conducted. The intent was to collect information from the firefighter perspective during a live fire event. The results show that visibility in the fire area was reduced to as low as one foot-candle. Sound pressure never exceeded 102 dB. Peak arm and leg temperatures measured within the bunker gear were 57°C and 45°C, respectively.

This test provides a starting point for virtual environment sensor development. Light intensity, sound pressure and temperature parameters for a typical scenario are available to serve as a basis for sensor specification.

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The Proceedings on the Damage Control/Fire Fighting into the 21st Century Workshop report (NRL/MR/6180-94-7643) by Patricia A. Tatem, dated 21 December 1994, presents a well thought-out approach to future Navy Damage Control needs and applications with consideration for manpower and budget trends. Training in the virtual environment is one aspect considered essential to meet the demands of the twenty-first century Navy. Benefits to be realized by virtual reality training are:

- Decreased trainer development and acquisition costs
- Decreased trainer operation and maintenance costs
- Reduced physical requirements: size, weight and power
- Deployable, available
- Enhanced training: provide an illusion of "being there" and affecting changes
- Preserve perishable training expertise
- Provide consistent and verifiable training
- Reduce the time to acquire a given proficiency level

To achieve these benefits in Damage Control fire fighting, a virtual reality trainer is needed with the necessary sense stimuli and activity response to effect total immersion. A three phase development process is being instituted to meet this need. The first step is to better understand and quantify sensory input to the firefighter (Phase I). Phase II involves sensor development and test based on the criteria devised in Phase I. The entire project culminates in Phase III where a user functional prototype is developed. The result is a safe, mobile and effective fire fighting trainer that can adapt to Navy and civilian requirements.

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SUMMARY

Four Class A live fire structural tests were conducted to collect sight, sound and touch (temperature) information from the firefighter's perspective. Touch (force) information was beyond the scope of this project. Taste and smell senses were not considered for evaluation because they are primarily influenced by the firefighter's air supply. Humidity within the fire fighting ensemble was not measured and was assumed to be 100%, as typically valued in the fire fighting test community. The purpose of evaluating firefighter sensory input was to provide a basis for virtual environment (VE) sensor development. The emphasis was on temperature since sight and sound capabilities were already well established in the VE industry.

Test firefighters wore Janesville bunker gear with interior temperature sensors placed at the front upper arms and front upper thighs. An exterior reference thermocouple was placed at the chest level. Fire area temperature conditions were measured with sensors placed at various vertical intervals in the fire room; and in the proceeding rooms for the fourth burn. Additionally, firefighters wore a helmet mounted video camera, a photocell at the bottom of the face mask, and a microphone by the left ear.

Firefighters spent no longer than 2.4 minutes performing fire fighting activities within any of the structures. Interior bunker gear temperature peaked at 57°C, which was 20°C above the initial temperature. The peak rate was 0.67°C/sec. The highest sound pressure was 102 dB. The lowest light intensity was 1 foot-candle.

The test results can be used as a basis for sensor design requirements. Recommend that bunker gear be modified to provide the temperature sensory input for fire fighting VE. Purchase and integration of sight and sound equipment should be delayed until the temperature concept is demonstrated.

1.0 INTRODUCTION

This report is a result of the Small Business Innovation Research Program (SBIR) Solicitation Number N94-249 Phase I contract award for Simulation of Fire in a Virtual Environment. The intent of this project is to provide realistic Damage Control fire fighting training that is safe, reduces training costs and enhances fleet readiness. The new training technology would also be available for commercial integration into the civilian professional fire service.

The objective of the Phase I project was to collect data to provide insight for requirements needed in Phase II sensor development. The testing described in this report was a result of staged fire fighting events performed by the Orange County (Florida) Fire and Rescue Division. The test site was a condemned block of frame houses where data were collected from a total of four instrumented firefighter live fire tests. Live fire heat, sound and light information, predominately from the firefighter perspective, was obtained. Global Technology Associates, Inc. and the University of Central Florida/Institute for Simulation and Training conducted the research burns on 27 and 28 March 1995 in Taft, Florida.

2.0 TEST SETUP

The test was setup to acquire live fire environment information from the firefighter's perspective. Instrumentation was located to characterize the fire and to sense what the firefighter sees, hears, and feels with respect to heat. A list of equipment and instrumentation is presented in Table 1. Detailed specifications for the test bunker gear are presented in Enclosure 1.

Two wood frame houses were used to conduct four live fire tests. A corner in a room at the rear of each house was selected for starting the fires. One to one-and-a-half bales of fluffed virgin straw (not hay) was scattered across the floor in a pile about 6 feet long by 3 feet wide by 2 feet deep. The straw was the fuel load for the test, not the house. This particular straw had hollow stalks that enabled it to burn hot and fast. The base of the straw pile was ignited by a hand held propane torch or an "Aim-A-Flame". This ignition served as the T-0 stopwatch synchronization time for all data recording groups. Data collection tasks were divided among three groups.

The audio/visual group was responsible for instrumenting the test firefighter with a photocell, a wireless microphone system, and a helmet mounted black and white CCD video camera as shown in Figure 1. The photocell was taped to the outside bottom center of the face mask. Photocell resistance information was sent via hardwire to a remote digital multimeter. Resistance was recorded at various times from fire start to firefighter exit. The wireless microphone transducer was taped to the Nomex hood exterior next to the left ear. Audio and video

information were sent to a VHS recorder approximately 100 feet away.

The temperature group instrumented the fire rooms and test firefighters with type-K thermocouples (Ref. Figures 1 and 2). Four thermocouples were mounted vertically in the fire room along the wall between the doorway and outside wall. Mounting intervals relative to the floor were 22 inches, 44 inches, 66 inches and 90 inches. For the fourth burn, two thermocouples each were mounted in the first and second rooms against the rear walls between the doorway and outside wall. The thermocouples were three feet and six feet above the floor. One remote datalogger recorded fire room temperatures while another (burn 4 only) recorded the non-fire room temperatures. Test firefighters were equipped with seven thermocouples and a portable datalogger. Thermocouples were placed in the following locations:

- on the Nomex hood exterior next to the right ear (shielded by helmet flap)
- on top of the Nomex hood (shielded by the helmet)
- on the bunker gear jacket exterior at chest level
- between the firefighter's clothing and the bunker gear interior surface --
    - between the shoulder and elbow on the forward facing arm surfaces
    - on the forward facing upper surface of the thighs

The spotter group noted the time of test firefighters at predetermined locations. The five primary locations were the first room doorway, near the middle of the first room, the second room doorway, near the middle of the second room, and the fire room doorway. Figure 3 illustrates position call-outs.

3.0 TEST DESCRIPTION

Once the instrumentation was setup, a fire fighting hose team was assembled on the test house porch. The order of the team was nozzleperson, lieutenant, instrumented firefighter, safety officer, and observer (spotter). The fire load was then ignited and given time to produce heat and smoke. All data collection timing was synchronized at the moment of fire ignition. Next, the front door was opened. Burns 3 and 4 had positive pressure ventilation started just prior to the team entering the house. On command the team proceeded to the fire, while the observer radioed instrumented firefighter locations . Firefighters were low to the floor as they progressed to the fire, typically moving on their knees. Upon reaching the fire room entrance the nozzleperson sprayed the area until thermal equalization was achieved. Fire load material was subsequently dispersed with fire hose stream pressure. When no further fire glow was observed, the team retreated back to the front porch. Thermoscan tympanic temperature measurements of the test firefighter were made before and immediately after the fire.

Each house was used twice for testing. All windows and doors were closed except for the

front door after team entry. House number 322 was used the first day. Firefighter/Engineer Henry Butts was the instrumented firefighter for the mid morning test. Lieutenant Tammy Wunderly was the instrumented firefighter for the early afternoon test. House number 315 was similarly used the following day. The instrumented firefighter was assisted by the safety officer in carrying the instrumentation cabling (video and photocell). All firefighters carried flashlights. The safety officer also carried an operating strobe as a beacon for disoriented individuals.

4.0 TEST RESULTS

The test event time history for Burns 1 through 4 is presented in Table 2. Pre and post test tympanic temperature data are presented in Table 3. Measurements of light intensity and sound pressure are presented in Tables 4 and 5. House and firefighter temperature plots are shown in Figures 4 through 9. Corresponding temperature data are presented in Tables 6 through 22. Tables 23 and 24 present bunker gear temperature extremes, durations and rates.

The intense smoke had a dramatic effect on light intensity as soon as the house was entered. Visibility near the fire area was reduced to as little as one foot-candle. Sound pressure achieved a high of 102 dB. Sound pressure maximums were typically reached near entering and exiting the house. Maximum sound pressure near the fire area was 95 dB. Because of the low approach by the firefighters, the 44 inches stationary thermocouple data was considered to correspond best with the chest and arm temperatures. Maximum 44 inches temperature for the fully involved fire was 826°C, and for the typical test fire was 549°C. The highest Room B temperature was 155°C at 36 inches. Peak external chest and interior arm temperatures were 56°C and 57°C, respectively. Maximum 22 inches temperature for the fully involved fire was 794°C, and for the typical test fire was 248°C. The peak thigh temperature was 45°C. Interior bunker gear maximum temperature differential (20°C) and rate (0.67°C/sec) all occurred in the upper arm area.

5.0 DISCUSSION OF RESULTS

There were weaknesses in instrumentation selection and calibration which made data certainty difficult to ascertain. Initial readings from the temperature sensors seemed to correlate well with the estimated weather conditions; thus, there was confidence the instrumentation was functioning within reason. Documentation of equipment and instruments were not adequate for traceability. Test procedures and control were difficult to implement because of concurrent OCFRD training and other commercial tests.

The primary task of the test firefighter was to move the instrumentation tether with the assistance of the safety officer. Suspect the close working proximity to the safety officer produced erroneous photocell data in the fire area because of exposure to the strobe light. (Strobe lights are

not normally used outside the training environment.) Lack of video hues made it difficult to precisely determine light sources. The video did show a dark and confusing environment with people rarely visible through the smoke. Spotting and relaying firefighter location and time information could not be done accurately under these conditions. Location/time error was estimated at ± 5 seconds. The sounds most discernible from the video were the ventilation equipment near the house entrance, and firefighter conversation, movement and breathing.

Not all fires proceeded as the description would imply. Burns 2 and 3 exceeded the intended fuel load by allowing too much time before engaging the fire, and became fully involved. The Burn 2 fire spread from the room of origin which proved detrimental to the test. The test firefighter was unable to proceed past point 4 before withdrawing because the trainee nozzleperson became hot and disoriented and abandoned the scene. Suspect room temperature instrumentation was damaged from the severity of the fire which caused the loss of data. Fire room temperature data from the other burns were partially lost because the thermocouple junctions opened as indicated by eccentric datalogger values.

The external chest thermocouple peak temperature was lower than peak interior bunker gear temperature for Burns 1 and 3. It was expected that the exposed thermocouple would always read higher than the protected thermocouples. This not being the case suggested that there was an imprecise correspondence between the exterior and interior thermocouples. Circumstances could be envisioned where the test firefighter, turning towards the safety officer, would block the chest thermocouple while leaving the arm thermocouple exposed towards the fire. The position among the other firefighters could also produce a shielding effect.

Firefighter interviews indicated that heat was most noticeable where insulation was diminished, especially by stretching or creasing the bunker gear. These areas include the knees, hips, elbows, front of the shoulder and face. Head and ear thermocouples were not good indicators of thermal input to the firefighter because they were placed outside the hood. No firefighter expressed any discomfort in the head and ear locations.

6.0 CONCLUSION

Four live fire tests were conducted and instrumented firefighter data were collected. Not all tests proceeded as planned, but sufficient data were collected to satisfy the test objective. Using a fire fighting team provided valuable insight into the effects of group dynamics on temperature variations. The information obtained in these tests can be used as a basis for establishing fire fighting virtual environment (VE) development criteria.

7.0 RECOMMENDATIONS FOR SIMILAR TESTS

The following recommendations are offered for improved data collection and analysis.

- Establish procedures that are understood and approved by all cognizant and involved individuals.
- Use NIST traceable measuring instrumentation.
- Conduct firefighter interviews immediately after the test.
- Locate firefighter thermocouples in heat sensation and heat stress areas.
- Opposing interior/exterior thermocouples should be used on the firefighters.
- Use telemetry or concealable portable instrumentation for the firefighter (no tether).
- If a tether must be used, associate it with the hose and a quick release connector.
- Use a color video camera to better pick up image subtleties.
- Collect all data continuously with a common time base.
- Collect and analyze data per common standards like MIL-STD-1474 for sound pressure.
- Use remote locating instrumentation rather than a spotter to determine firefighter position.
- Use instrumentation reference standards: video color chart, fire room microphone, etc.

8.0 RECOMMENDATIONS FOR FIREFIGHTER VE DEVELOPMENT

Military and commercial interests have been driving audio and sound VE development for a long time. However, there are two other aspects that have not received sufficient attention which are necessary for firefighter VE. These aspects are safety and temperature simulation.

Human physiology requires further study to determine characteristics that indicate when it is no longer safe to continue in the fire fighting environment. The Naval Health Research Center (NHRC) in San Diego, CA is pursuing research in this area, but results are still some time away. A cooperative research and development agreement (CRDA) may be necessary to accelerate research and gain access to the information.

Temperature simulation should be the focus of Phase II sensor development. Firefighter bunker gear could be modified for this purpose. The removable liners in bunker gear would facilitate this conversion by offering a platform for flexible heater installation. The suit should be capable of producing heat stress as well as the feeling of heat, which means both body water mass and prominent bone areas would require heat input. Suggested vendor products that may assist in temperature simulation development are as follows:

Vendor	Phone Number	Product
Lion Apparel	(800) 421-2926	bunker gear and bunker gear research
Aplix Fasteners	(704) 588-1920	high temperature hook & loop fasteners
Elmwood Sensors	(401) 727-1300	heater design and control
Minco Products	(612) 571-3121	heater design and control
Mini Mitter	(541) 593-8639	physiological monitoring/telementry
Green Spring Comp.	(415) 327-1200	miniature data acquisition computers
Omega Engineering	(800) 826-6342	temperature instrumentation

Purchasing audio/visual VE equipment should be delayed until desired temperature simulation capabilities are satisfactorily demonstrated. This would prove validity of the concept prior to the most costly expenditures of material and labor. Detailed audio/visual recommendations from the Institute for Simulation and Training are presented in Enclosure 2.

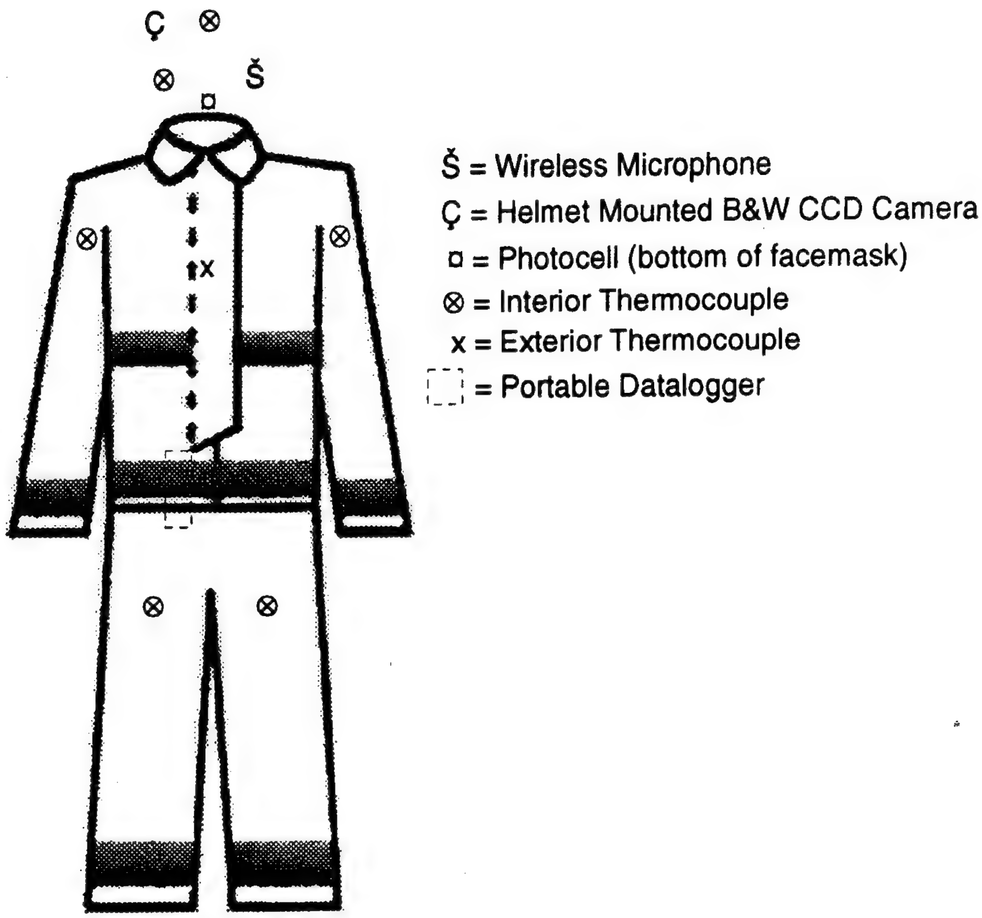
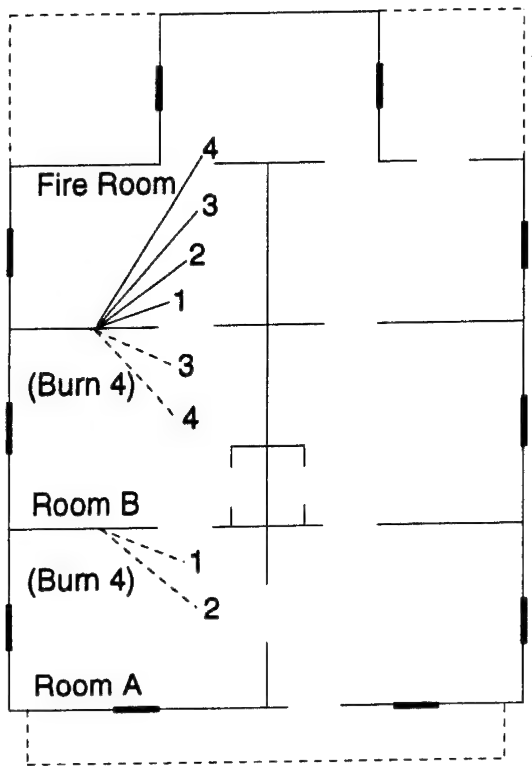
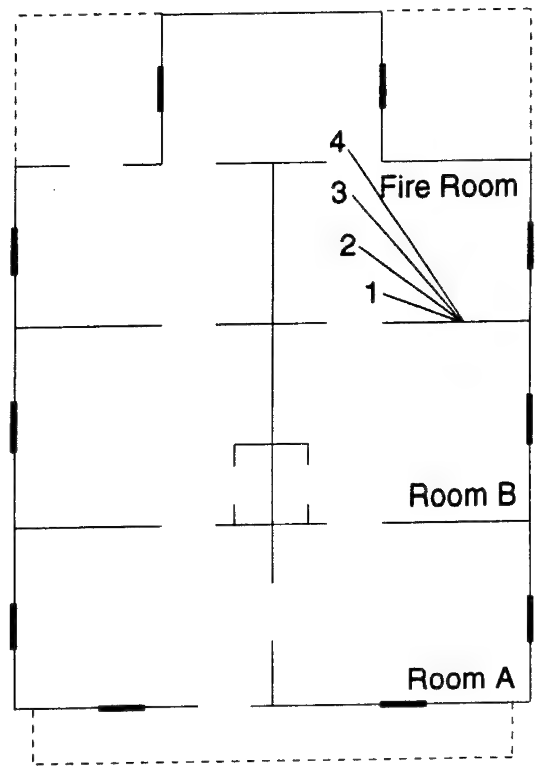


Figure 1. Firefighter Instrumentation.

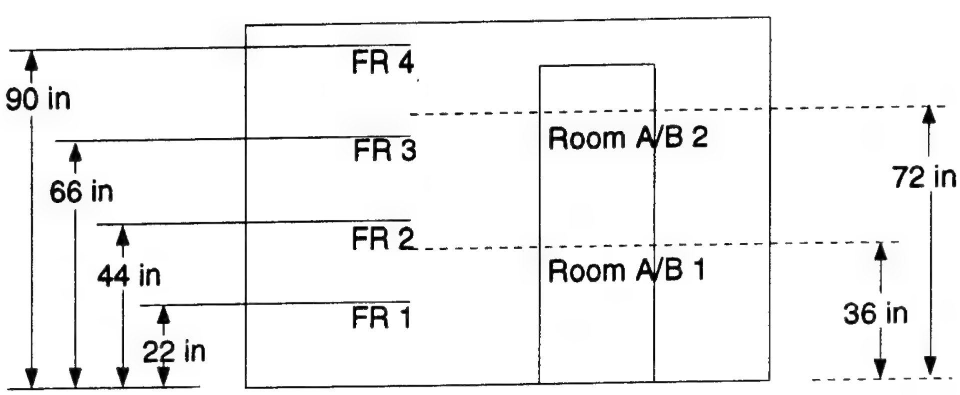
The top interior thermocouple was taped to the Nomex hood under the firefighter's helmet. The interior thermocouple next to the ear was taped outside the Nomex hood, and shielded by the helmet flap. The microphone was similarly placed by the opposite ear. Other interior thermocouples were attached to the bunker gear between the inner most liner and the firefighter's clothing.



Floor Plan for House Number 315



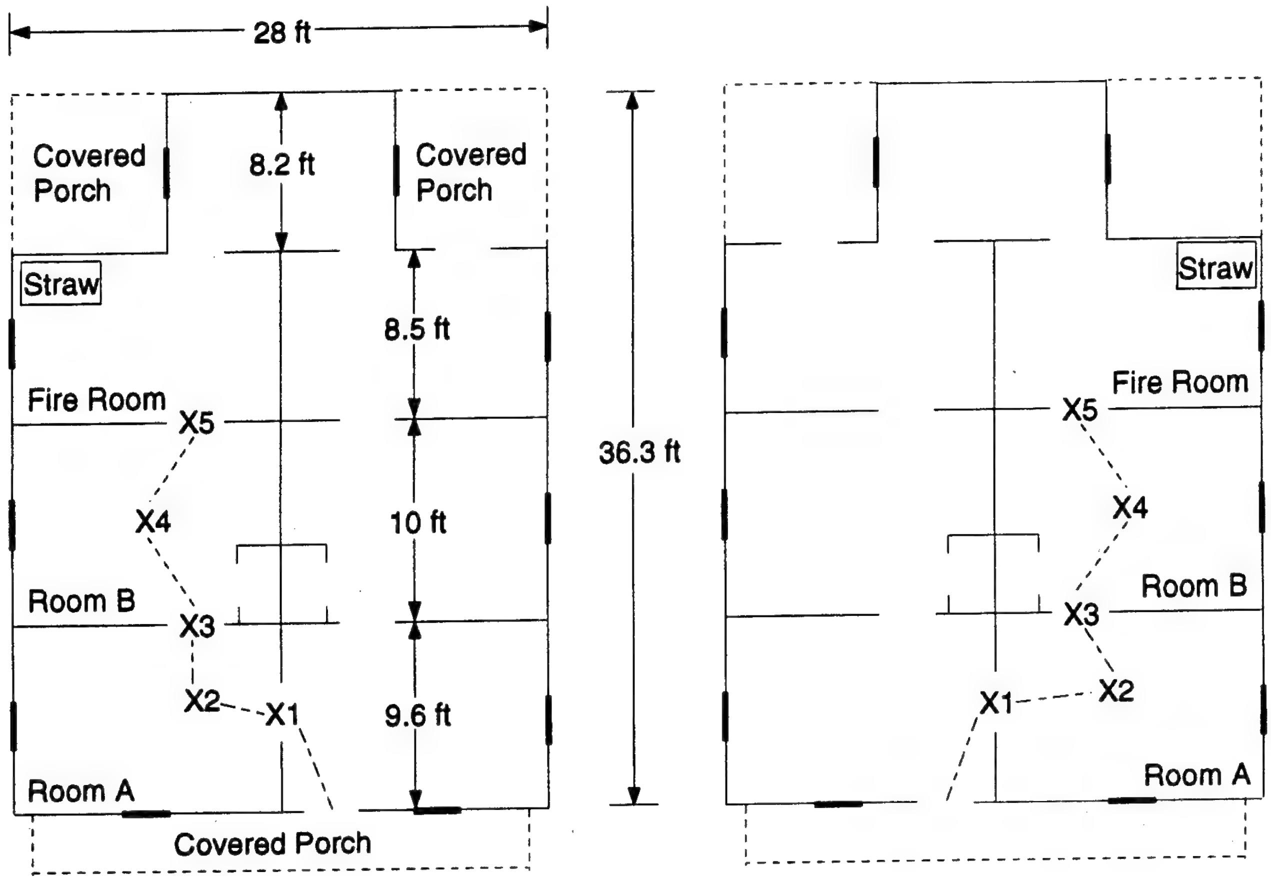
Floor Plan for House Number 322



Typical Thermocouple Vertical Spacing

Figure 2. House Thermocouple Locations.

All thermocouples were type-K. The thermocouples in rooms A and B were used only in Burn 4. FR = Fire Room; Room A/B = Room A and Room B. Thermocouples are indicated by numbers 1 through 4.

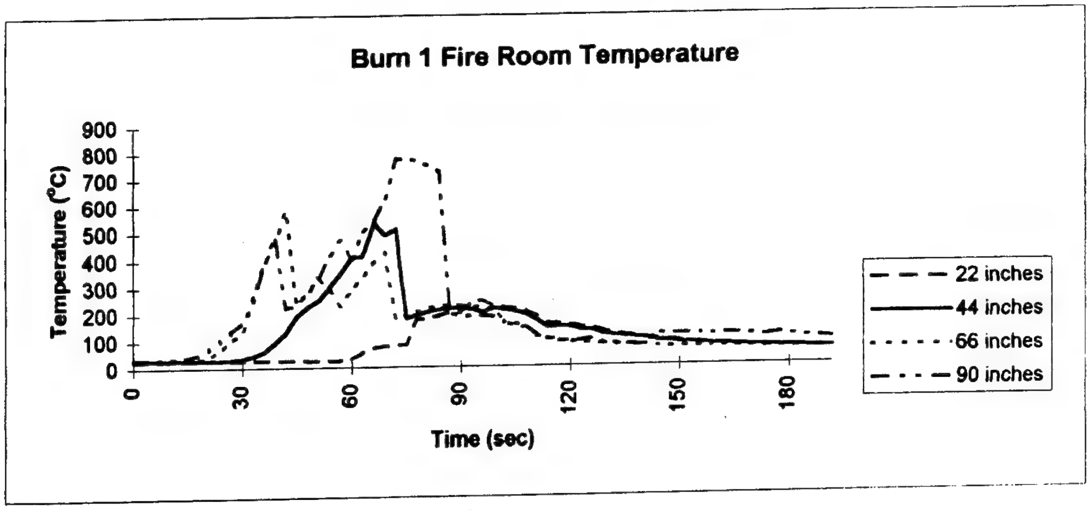


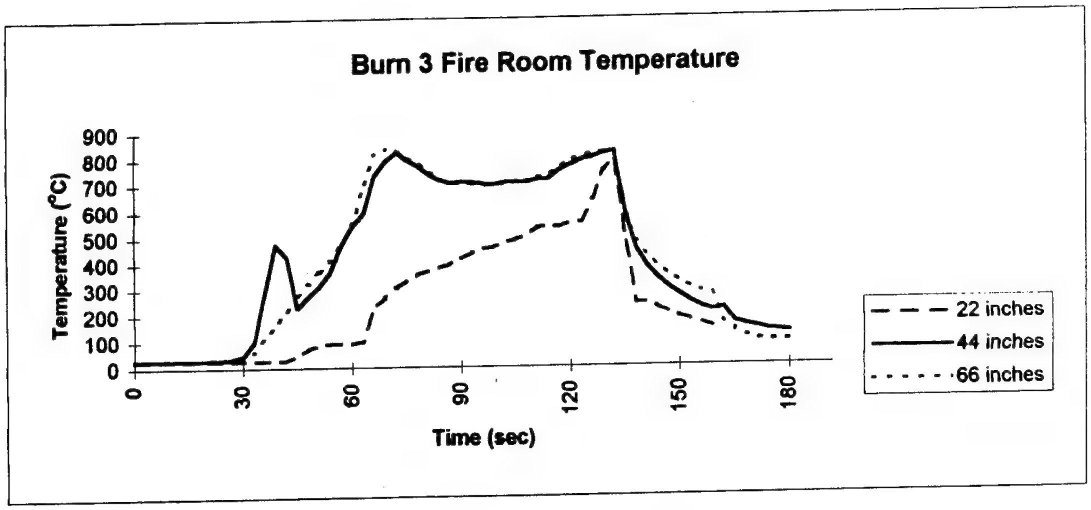
Floor Plan for House Number 315

Floor Plan for House Number 322

Figure 3. Firefighter Tracking Points.

Instrumented firefighter tracking points are indicated by a " X# ". Firefighters always faced the fire whether advancing or retreating. For safety reasons the instrumented firefighter followed behind the nozzleman and lieutenant. Each house was used for two fire tests (same room). Burns 1 and 2 were conducted mid morning and early afternoon of the first day on house 322. Burns 3 an 4 followed the next day on house 315. Fire activities were performed by the Orange County Fire and Rescue Division. Firefighter/Engineer Henry Butts was the test firefighter for odd numbered burns. Lieutenant Tammy Wunderly was the test firefighter for even numbered burns.





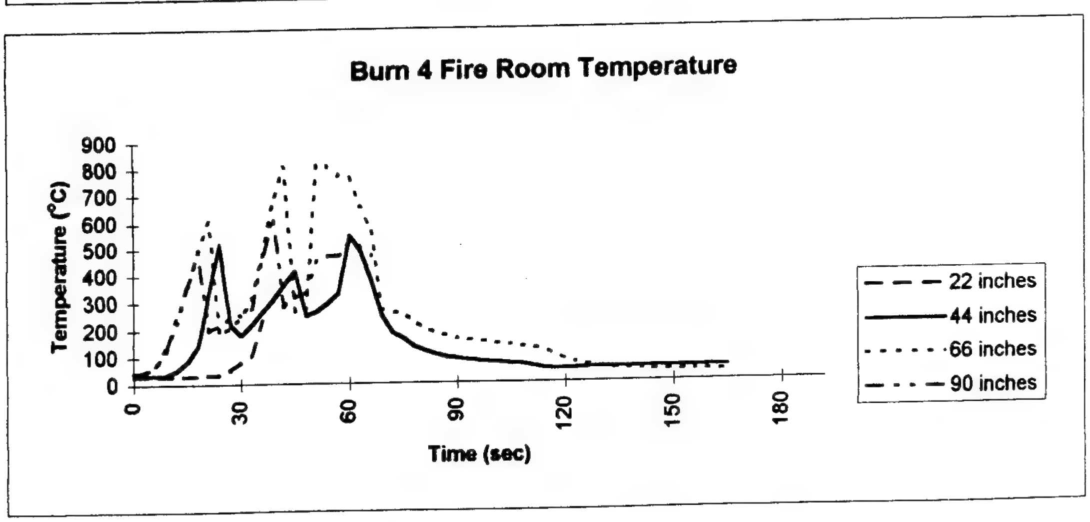
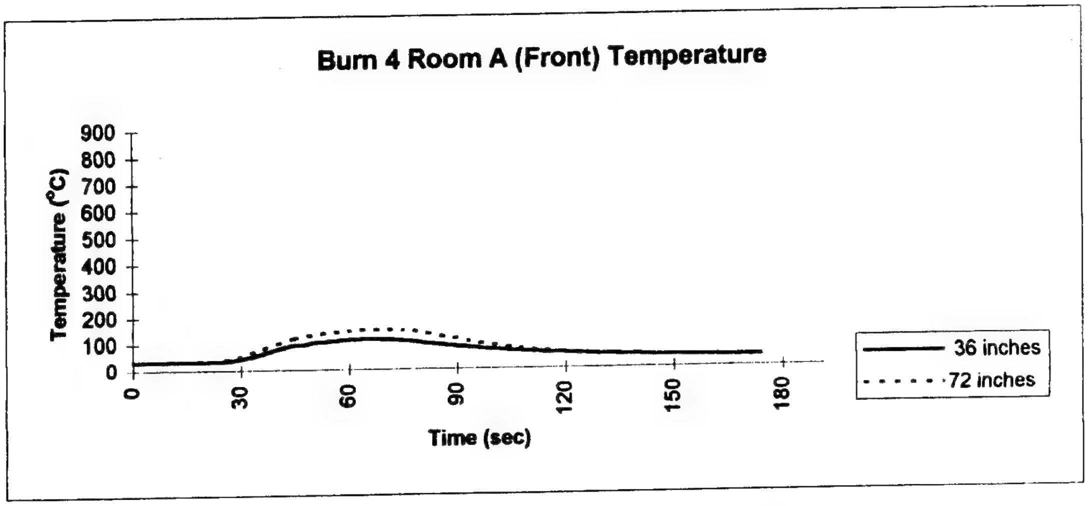
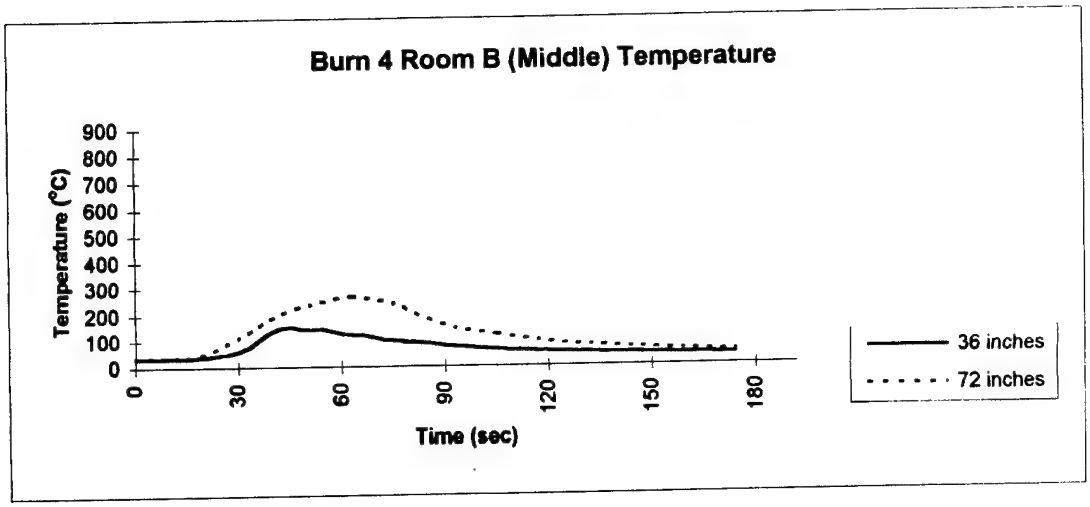


Figure 4. Fire Room Temperature Plots.

No data available for Burn 2. Burn 3 became a fully involved fire.





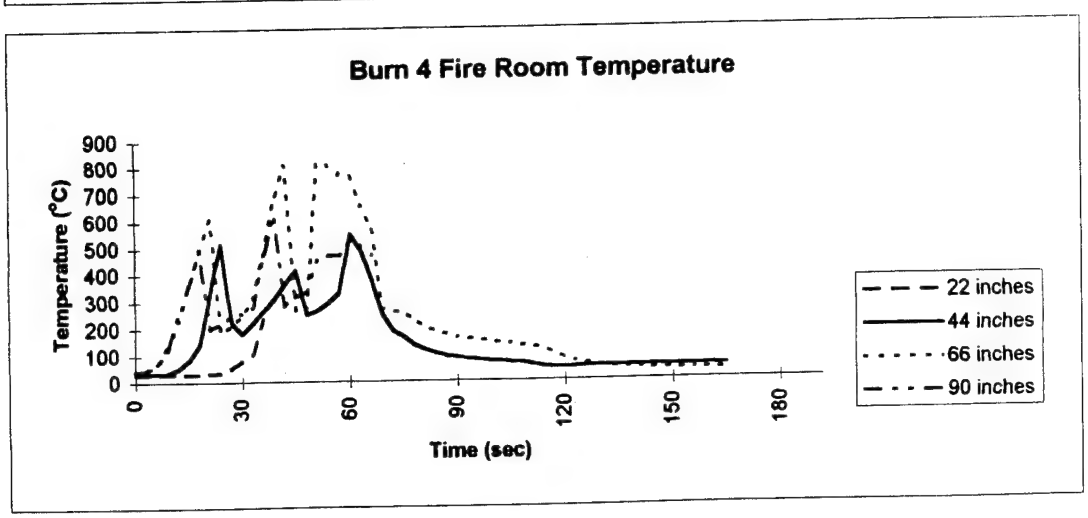
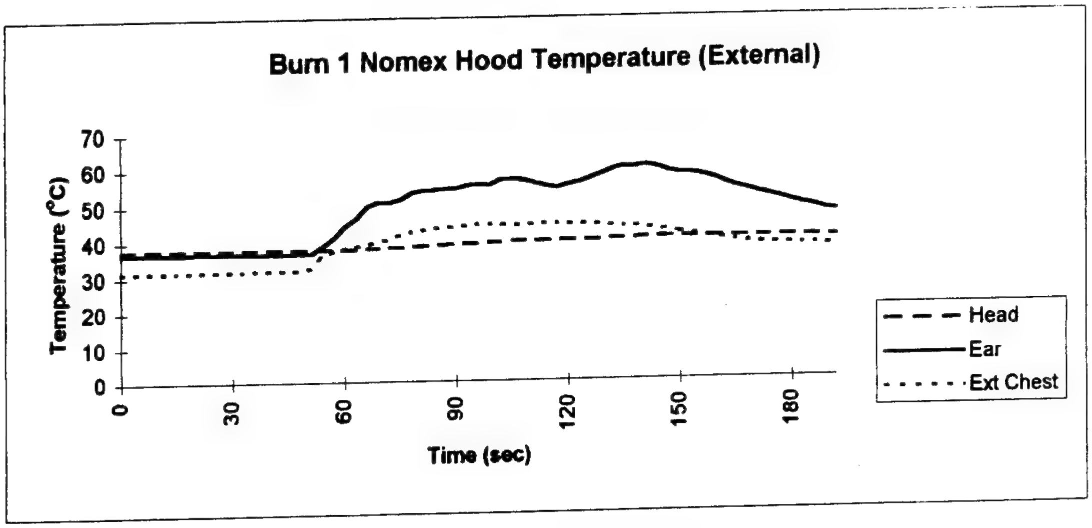
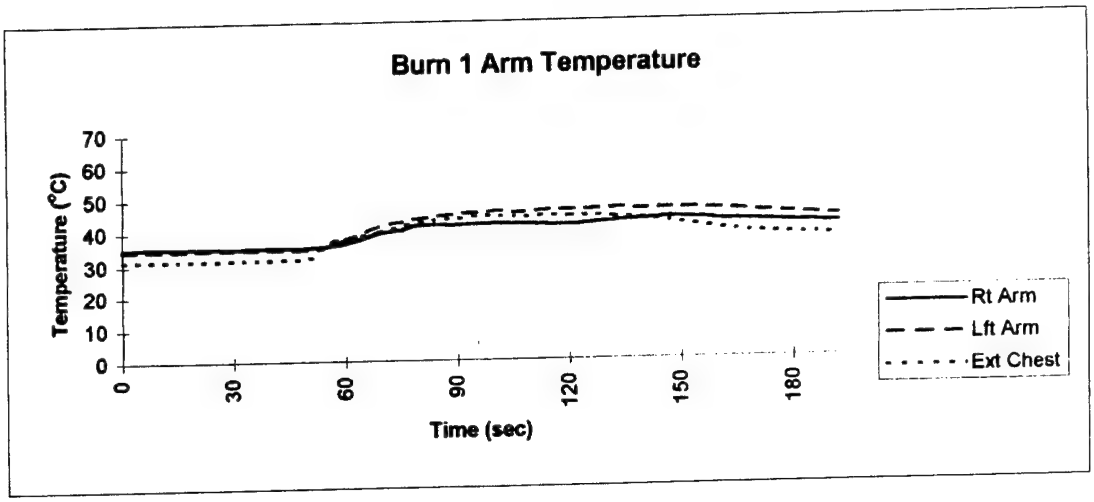


Figure 5. Burn 4 Activity Rooms Temperature Plots.





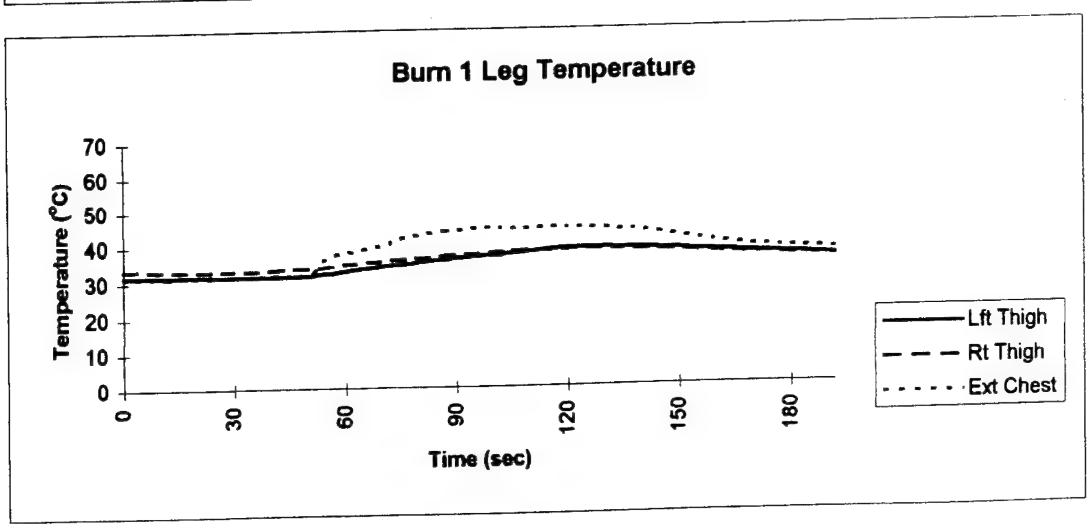
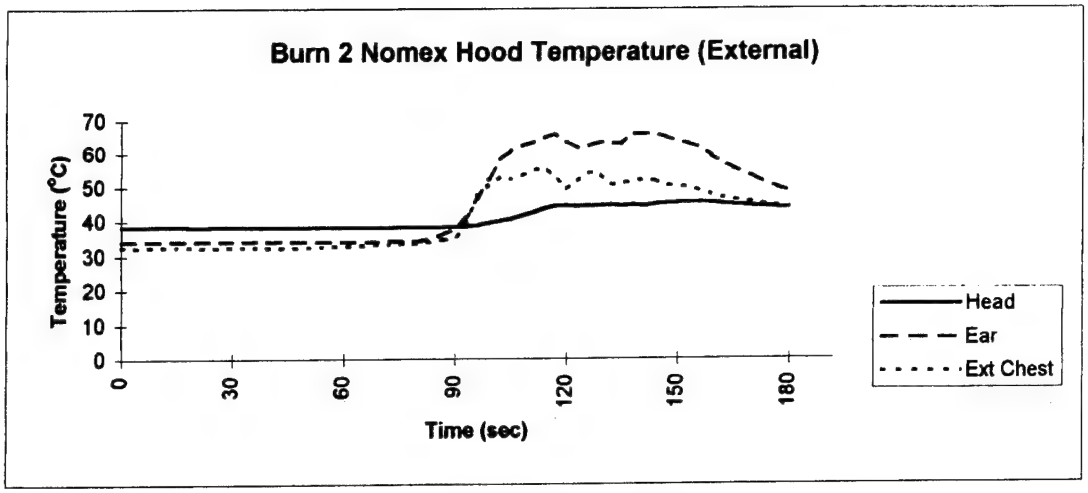
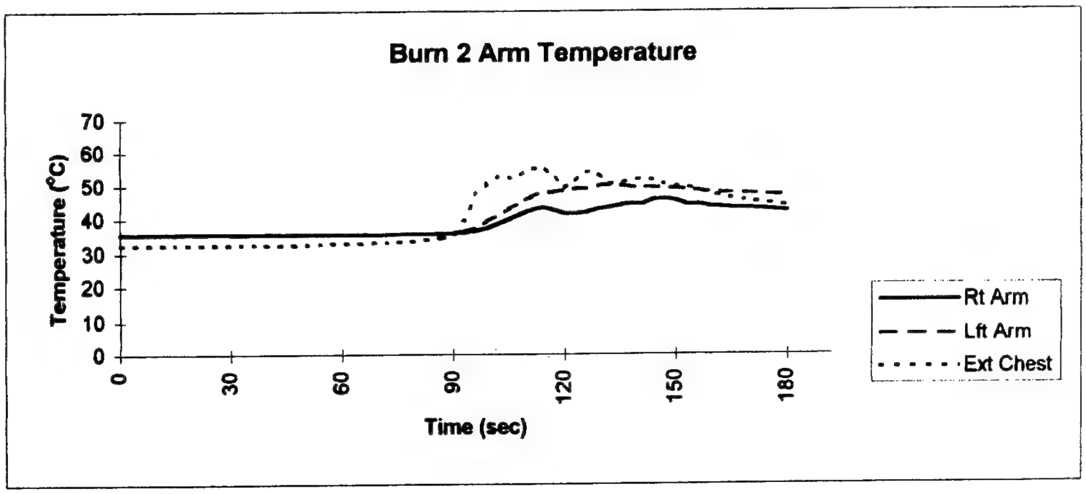


Figure 6. Burn 1 Firefighter Temperature Plots.





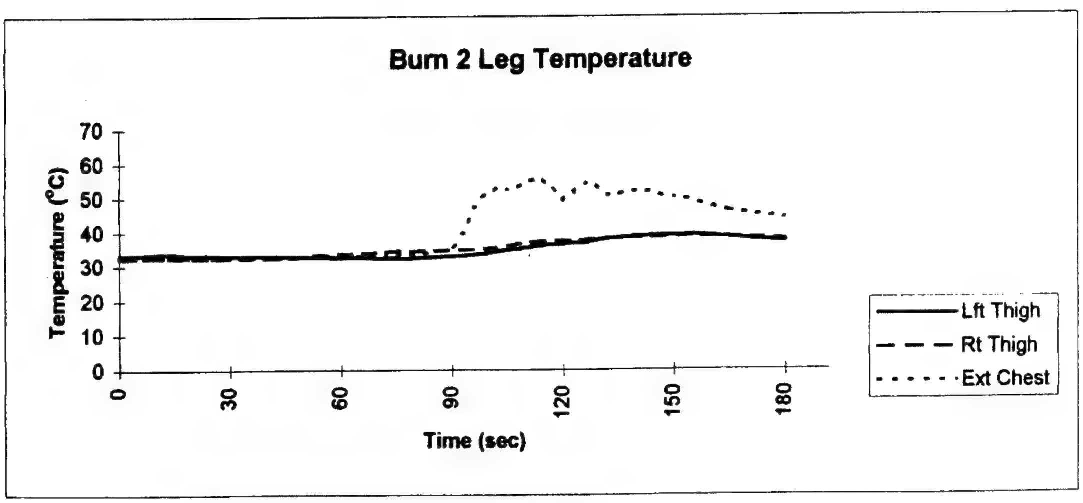
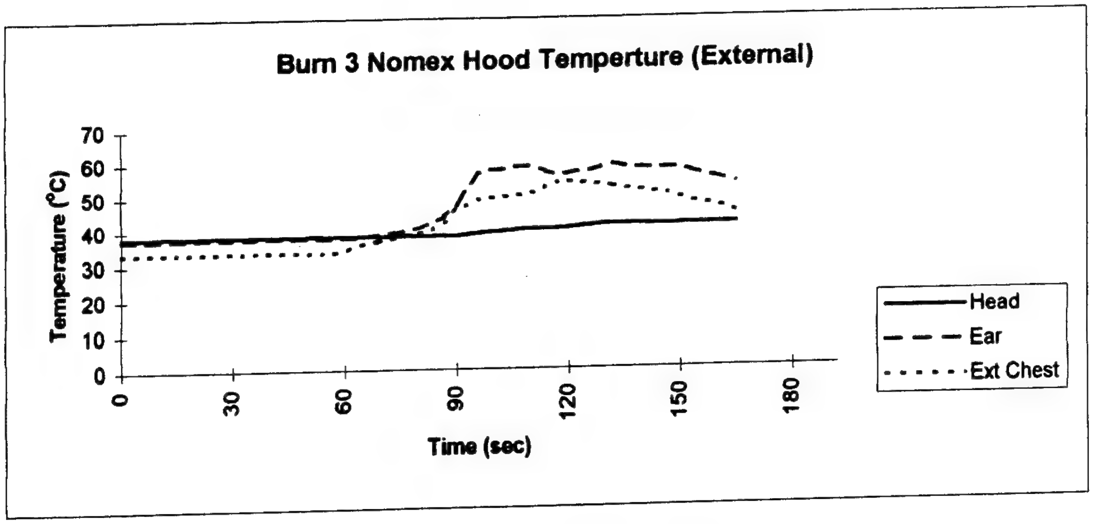
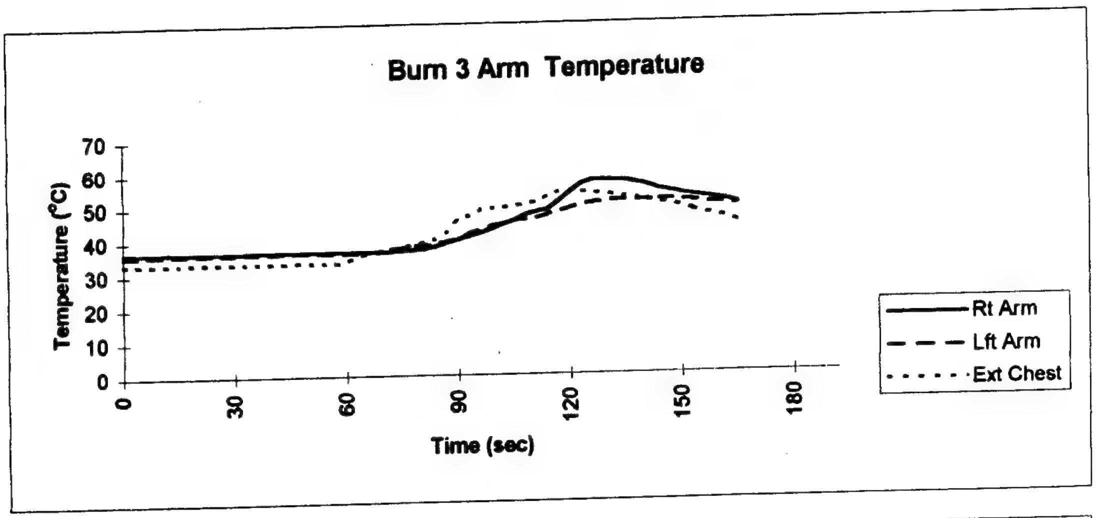


Figure 7. Burn 2 Firefighter Temperature Plots.





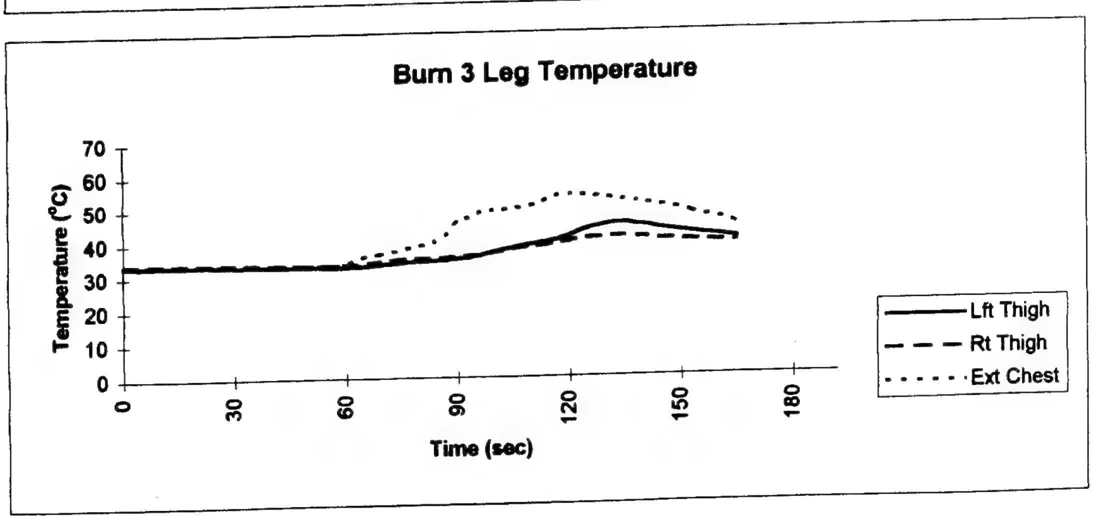
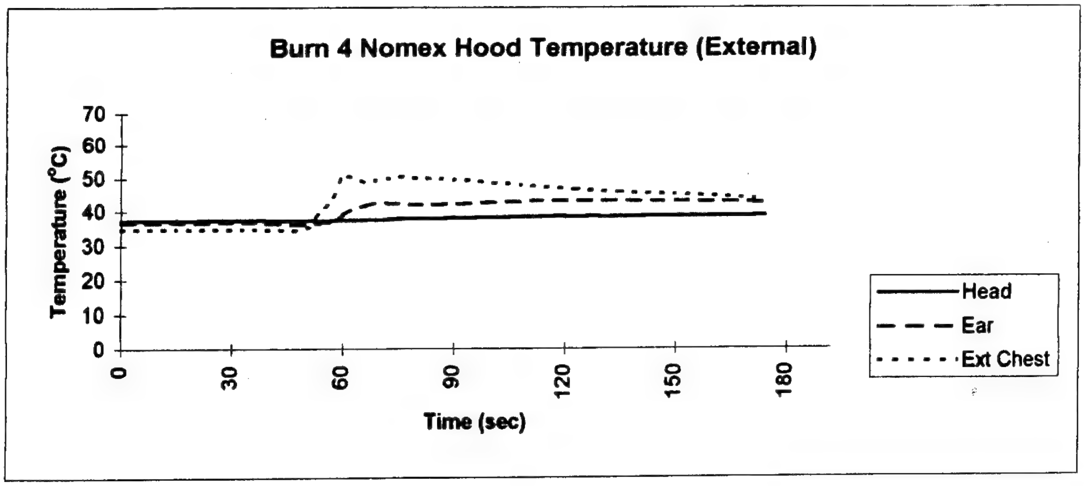
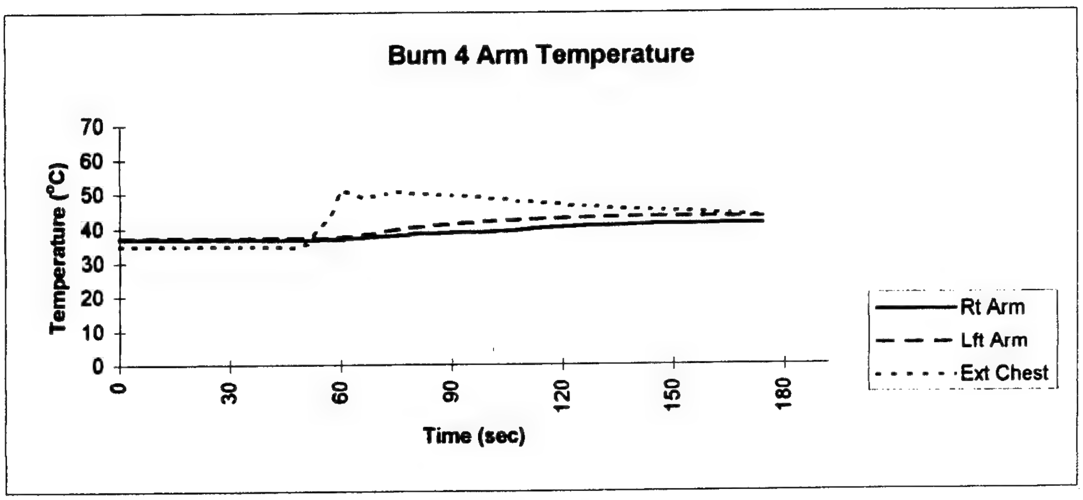


Figure 8. Burn 3 Firefighter Temperature Plots.





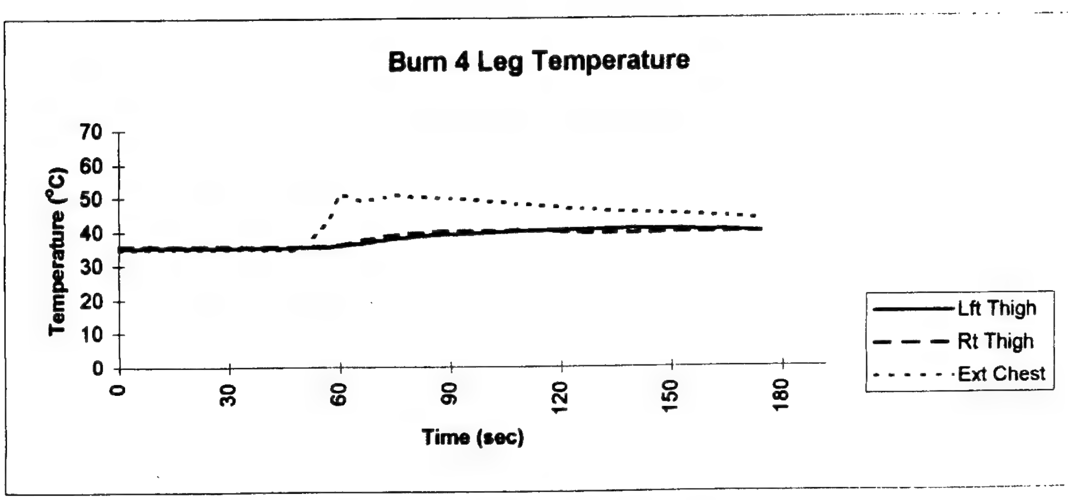


Figure 9. Burn 4 Firefighter Temperature Plots.

Table 1. Equipment and Instrumentation

Description	Manufacturer and Model
Dataloggers (3)	Campbell Scientific 21X Micrologger
Thermocouples	Type K (twisted junction)
Digital Thermometer	Thermoscan
Digital Sound Level Meter	Realistic Model 33-2055
FM Wireless Microphone System	Radio Shack Model 32-1229
CCD Video Camera (B & W)	Watek Model 902
Video Camera Power Supply	Unknown
VHS Video Recorder	LXI 4 Head VCR
Monitor/Speaker	Unknown
Keyboard	Unknown
Cadmium-Sulfate Photocell	Archer Model 276-1657
Digital Multimeter	HP Model 3435A
Light Intensity Meter	Unknown
Synchronized Stopwatches	Unknown
Bunker Suit (2 Piece)	Lion Apparel Model Janesville
- Moisture Barrier	- Gortex
- Thermal Liner	- Nomex Quilt/Gortex
- Outer Shell	- 7.5 ounce Nomex
Helmet	Unknown
Gloves	Unknown
Boots	Unknown
Face Mask and Pack	Scott
Air Tank	Unknown

Calibration

Measuring instruments were assumed to be functioning within manufacturers specifications. However, additional procedures were performed for light intensity and sound calibrations.

Light Intensity: The photocell was mounted to the light intensity meter. The change in light intensity versus photocell electrical resistance was plotted and found to correlate with the equation: Foot Candles = $1607(k\Omega)^{-0.983}$. Light intensity values were derived from this equation.

Sound Pressure: A keyboard was used to generate five distinct sounds at different volumes. The sounds were recorded on video tape, and the dB values of the volume annotated. Playback sound through the video monitor speaker was adjusted until the dB volume was matched.

Table 2. Test Event Time History

Event	Burn 1 (sec)	Burn 2 (sec)	Burn 3 (sec)	Burn 4 (sec)
Initialize Rooms A/B Datalogger	NA	NA	NA	-1065
Initialize Fire Room Datalogger	- 705	ND	-1223	- 915
Initialize Bunker Gear Datalogger	- 825	- 765	-1044	- 735
Pre-test Thermoscan Temperature	- 751	- 708	- 563	- 559
Start Fire (synchronize timing)	0	0	0	0
Open Door	39	70	51	33
Enter House	51	87	60	36
Tracking Point 1 (advance)	ND	ND	75	39
Tracking Point 2 (advance)	63	90	84	42
Tracking Point 3 (advance)	66	99	96	48
Tracking Point 4 (advance)	72	114	105	51
Tracking Point 5 (advance)	75	NA	114	66
Fire Room	NA	NA	NA	84
Tracking Point 5 (retreat)	NA	NA	NA	102
Tracking Point 4 (retreat)	NA	NA	NA	159
Tracking Point 3 (retreat)	NA	126	NA	ND
Tracking Point 2 (retreat)	NA	NA	NA	165
Tracking Point 1 (retreat)	NA	NA	NA	ND
Exit House	192	180	165	174
Post-test Thermoscan	229	265	218	265

Notes:
1. NA = Not Applicable. Data collection was not intended for the specified event.
2. ND = No Data. Some fire fighting maneuvers precluded event time recording.
3. Burn 2 experienced a fire room thermocouple instrumentation failure.
4. Spotter time/position data was relayed to instrumentation groups by radio.

Table 3. Firefighter Tympanic Temperature Measurements

Temperature Measurements

	Burn 1	Burn 2	Burn 3	Burn 4
Firefighter	H. B.	T. W.	H. B.	T. W.
Pre-test Temperature (°C/°F)	36.2/97.2	37.1/98.7	36.6/97.8	36.8/98.2
Post-test Temperature (°C/°F)	37.7/99.8	37.5/99.5	37.4/99.3	37.6/99.7

When Temperature Measurements Were Made

	Burn 1	Burn 2	Burn 3	Burn 4
Before entering house (min.)	11.7	10.4	8.3	8.7
After exiting house (min.)	0.6	1.4	0.9	1.5
Activity time in house (min.)	2.4	1.6	1.8	2.3

Notes:
1. H. B. = Orange County Fire and Rescue Division Firefighter/Engineer Henry Butts.
2. T. W. = Orange County Fire and Rescue Division Lieutenant Tammy Wunderly.
3. General weather conditions: 32.5°C(90°F), 40% RH, Calm, Dry, and Clear.
4. Temperature measurements were made with a Thermoscan thermometer.

Table 4. Light Intensity Results

Burn 1 Time (sec)	Burn 1 Light (fc)	Burn 2 Time (sec)	Burn 2 Light (fc)	Burn 3 Time (sec)	Burn 3 Light (fc)	Burn 4 Time (sec)	Burn 4 Light (fc)	Location
0	1242	0	1205	0	1116	0	3175	Start fire
39	1079	70	171	51	1079	33	706	Open door
51	842	87	109	60	17	36	608	Enter house
57	546			75	3	39	300	Point 1 (advance)
63	584	90	5	84	1	42	1	Point 2 (advance)
						45	1	
66	1	99	5	96	93	48	367	Point 3 (advance)
		107	7					
72	1	114	3	105	1	51	3	Point 4 (advance)
						57	9	
						63	112	
75	1			114	4	66	167	Point 5 (advance)
78	*1*			*123*	*1*	72	14	
						78	15	
						84	9	Fire room
						96	1	
						102	1	Point 5 (retreat)
						108	2	
						114	4	
						123	1	
						129	3	
						135	3	
						144	8	
						150	1	
105	*161*			*135*	*2*	159	730	Point 4 (retreat)
108	*1*							
120	*1*	126	4					Point 3 (retreat)
140	*1*	*133*	*4*					
		159	*4*					
143	*17*	*162*	*76*	*153*	*553*	165	286	Point 2 (retreat)
156	*291*	*167*	*167*					
		170	*331*					
192	1079	180	813	165	834	174	1079	Exit house

Notes:

1. Firefighters advanced and retreated on their knees facing towards openings leading to the fire.
2. The instrumented firefighter was the third person in a five person team.
3. Burns 3 and 4 used positive pressure ventilation to reduce heat and smoke effects.
4. Burn 2 test firefighter advance stopped at Point 4. The fire room was entered during Burn 4, only.
5. Font "*123*" indicates an estimated location based on video, time and fire room data.

Table 5. Sound Pressure Results

Burn 1 Time (sec)	Burn 1 Sound (dB)	Burn 2 Time (sec)	Burn 2 Sound (dB)	Burn 3 Time (sec)	Burn 3 Sound (dB)	Burn 4 Time (sec)	Burn 4 Sound (dB)	Location
0	72	0	93	0	81	0	76	Start fire
39	92	70	86	51	95	33	100	Open door
51	94	87	93	60	98	36	94	Enter house
57	90			75	93	39	96	Point 1 (advance)
63	89	90	91	84	88	42	93	Point 2 (advance)
						45	91	
66	89	99	87	96	96	48	91	Point 3 (advance)
		107	86					
72	91	114	93	105	95	51	92	Point 4 (advance)
						57	91	
						63	92	
75	90			114	88	66	92	Point 5 (advance)
78	*85*			*123*	*93*	72	88	
						78	86	
						84	84	Fire room
						96	86	
						102	94	Point 5 (retreat)
						108	92	
						114	91	
						123	91	
						129	94	
						135	94	
						144	94	
						150	90	
105	*82*			*135*	*91*	159	95	Point 4 (retreat)
108	*91*							
120	*80*	126	95					Point 3 (retreat)
140	*81*	*133*	*91*					
		159	*87*					
143	*81*	*162*	*91*	*153*	*95*	165	96	Point 2 (retreat)
156	*75*	*167*	*95*					
		170	*92*					
192	90	180	86	165	99	174	102	Exit house

Notes:
1. Noise was generated primarily by firefighter command/response and team activities.
2. The instrumented firefighter was the third person in a five person team.
3. Burns 3 and 4 used positive pressure ventilation to reduce heat and smoke effects.
4. Burn 2 test firefighter advance stopped at Point 4. The fire room was entered during Burn 4, only.
5. Font "*123*" indicates an estimated location based on video, time and fire room data.

Table 6. Burn 1 Fire Room Temperature Data.

Time (sec)	22 inches (°C)	44 inches (°C)	66 inches (°C)	90 inches (°C)
0	27	30	31	34
3	27	30	31	34
6	27	30	30	34
9	27	30	31	33
12	27	30	32	37
15	27	30	33	43
18	27	30	34	53
21	27	30	45	73
24	27	31	68	104
27	27	33	101	133
30	27	36	130	170
33	27	45	266	250
36	27	61	380	374
39	27	94	468	489
42	27	132	583	223
45	27	194	240	233
48	27	228	280	276
51	27	252	331	336
54	27	300	290	413
57	27	351	232	470
60	33	409	286	401
63	53	413	336	502
66	72	537	383	545
69	81	490	423	615
72	83	514	182	775
75	84	182	196	778
78	178	194	205	767
81	181	205	217	751
84	191	213	227	726
87	203	217	230	199
90	201	217	227	188
93	239	214	224	189
96	248	203	220	189
99	223	217	216	185
102	219	212	164	165
105	215	206	151	159
108	207	193	145	150
111	186	172	113	114
114	159	144	104	105
117	158	148	97	99
120	154	145	92	94
123	145	137	89	94
126	143	134	86	102
129	130	120	81	85
132	122	115	80	82
135	115	110	79	80
138	110	105	77	77
141	105	101	75	75
144	98	94	71	122
147	94	91	68	114
150	89	87	68	117
153	85	84	68	116
156	82	81	67	116
159	80	78	67	113
162	77	76	67	116
165	75	74	66	116
168	73	72	66	113
171	71	71	65	112
174	69	69	64	108
177	68	68	63	113
180	66	67	63	112
183	65	65	63	106
186	64	64	62	102
189	63	63	62	99
192	62	62	62	96

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 51 seconds after fire ignition.

Table 7. Burn 3 Fire Room Temperature Data.

Time (sec)	22 inches (°C)	44 inches (°C)	66 inches (°C)
0	28	31	30
3	28	31	30
6	28	31	30
9	28	31	30
12	28	31	30
15	28	31	30
18	28	31	30
21	28	31	30
24	28	32	30
27	27	36	33
30	27	47	40
33	27	101	64
36	27	285	110
39	27	476	161
42	28	429	216
45	49	230	276
48	72	272	323
51	86	314	368
54	91	368	410
57	92	472	468
60	93	543	551
63	99	590	686
66	227	735	816
69	265	792	840
72	302	826	833
75	331	797	806
78	357	772	786
81	368	739	750
84	380	717	722
87	394	703	702
90	417	708	704
93	438	706	703
96	454	700	697
99	461	697	694
102	476	706	702
105	488	708	705
108	504	707	708
111	531	716	724
114	541	718	729
117	534	755	759
120	550	774	792
123	552	795	807
126	638	803	818
129	751	818	823
132	794	827	822
135	505	586	587
138	243	452	478
141	241	385	428
144	225	339	383
147	204	301	347
150	188	272	320
153	172	244	301
156	160	223	285
159	144	210	272
162		219	168
165		163	129

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 60 seconds after fire ignition.
3. This fire became "fully involved." It was not under control prior to flashover transition like Burns 1 and 4.

Table 8. Burn 4 Fire Room Temperature Data.

Time (sec)	22 inches (°C)	44 inches (°C)	66 inches (°C)	90 inches (°C)
0	30	33	40	42
3	30	33	43	46
6	30	34	64	67
9	30	37	121	129
12	30	53	228	245
15	31	85	359	363
18	32	142	495	486
21	34	336	606	199
24	37	519	185	220
27	50	222	212	246
30	80	181	247	257
33	108	224	314	282
36	234	267	475	466
39		311	684	622
42		363	808	284
45		415	267	317
48		251	280	338
51		266	811	451
54		297	811	471
57		331	774	471
60		549	764	518
63		492	658	510
66		382	572	470
69		251	274	
72		186	264	
75		166	254	
78		136	227	
81		120	201	
84		106	187	
87		96	176	
90		89	166	
93		84	159	
96		79	153	
99		76	149	
102		73	144	
105		70	140	
108		68	134	
111		61	130	
114		52	120	
117		49	102	
120		49	85	
123		50	72	
126		51	63	
129		51	57	
132		51	53	
135		51	49	
138		52	46	
141		53	44	
144		53	42	
147		53	40	
150		52	39	
153		51	38	
156		51	38	
159		54	37	
162		54	37	
165		53	36	
168		52	36	
171		52	36	
174		50	36	

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.
3. After 48 seconds the data at 66 inches are hotter than the data at 90 inches. Suspect ceiling conduction cooling.
4. Missing data are the result of thermocouple malfunction.

Table 9. Burn 4 Room A (Front) Temperature Data.

Time (sec)	36 inches (°C)	72 inches (°C)
0	34	35
3	34	35
6	34	35
9	34	35
12	34	35
15	34	35
18	34	36
21	34	36
24	35	39
27	38	45
30	44	54
33	52	66
36	63	80
39	75	94
42	86	107
45	94	119
48	98	128
51	104	133
54	107	139
57	111	144
60	113	146
63	114	148
66	114	149
69	115	149
72	113	148
75	109	147
78	105	144
81	99	137
84	95	128
87	91	119
90	87	114
93	83	104
96	79	98

Time (sec)	36 inches (°C)	72 inches (°C)
99	76	92
102	73	86
105	69	81
108	66	76
111	64	71
114	61	66
117	59	63
120	58	60
123	56	57
126	54	54
129	52	52
132	51	51
135	50	49
138	48	48
141	48	47
144	46	46
147	45	44
150	44	43
153	44	43
156	43	42
159	42	41
162	42	40
165	41	40
168	40	39
171	40	39
174	40	38

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.

Table 10. Burn 4 Room B (Middle) Temperature Data

Time (sec)	36 inches (°C)	72 inches (°C)
0	33	36
3	33	36
6	33	36
9	33	36
12	34	38
15	34	38
18	39	45
21	41	54
24	46	73
27	51	94
30	61	112
33	76	131
36	104	158
39	131	181
42	149	203
45	155	220
48	147	232
51	144	239
54	147	250
57	137	255
60	128	265
63	124	267
66	122	265
69	114	258
72	104	251
75	99	243
78	95	229
81	93	208
84	89	189
87	85	175
90	79	162
93	75	149
96	73	141

Time (sec)	36 inches (°C)	72 inches (°C)
99	70	135
102	68	130
105	65	124
108	62	117
111	60	110
114	59	105
117	57	100
120	56	94
123	54	90
126	53	86
129	52	82
132	51	80
135	50	77
138	49	74
141	48	72
144	48	70
147	47	68
150	46	65
153	46	63
156	45	61
159	44	59
162	44	58
165	44	57
168	43	55
171	43	54
174	43	53

Notes:

1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.

Table 11. Burn 1 Hood Temperature Data.

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
0	38	37	32
3	38	37	32
6	38	37	32
9	38	37	32
12	38	37	31
15	38	37	32
18	38	37	32
21	38	37	32
24	38	37	32
27	38	37	32
30	38	37	32
33	38	37	32
36	38	37	32
39	38	37	32
42	38	37	32
45	38	37	32
48	38	37	32
51	38	37	33
54	38	39	36
57	38	41	37
60	38	44	38
63	38	46	39
66	38	50	39
69	38	51	40
72	38	51	41
75	38	52	42
78	38	53	42
81	39	54	43
84	39	54	43
87	39	55	44
90	39	55	44
93	39	55	44
96	39	56	45
99	39	55	45
102	39	57	44
105	40	57	44
108	40	57	44
111	40	56	45
114	40	55	45
117	40	55	45
120	40	55	44
123	40	56	44
126	40	57	44
129	40	58	44
132	40	60	44
135	40	60	44
138	40	60	44
141	40	61	43
144	40	60	43
147	40	59	42
150	40	58	42
153	41	58	41
156	40	58	41
159	40	57	40
162	40	55	40
165	40	54	39
168	40	53	39
171	40	53	39
174	40	52	39
177	40	51	38
180	40	50	38
183	40	49	38
186	40	49	38
189	40	48	38
192	40	47	37

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 51 seconds after fire ignition.
3. The thermocouples were on the Nomex hood exterior and covered by the helmet/flaps.
4. The chest thermocouple was used for external temperature reference.

Table 12. Burn 1 Arm Temperature Data.

Time (sec)	Rt Arm (°C)	Lft Arm (°C)	Ext Chest (°C)
0	35	35	32
3	35	35	32
6	35	35	32
9	35	35	32
12	35	35	31
15	35	35	32
18	35	35	32
21	35	35	32
24	35	35	32
27	35	35	32
30	35	35	32
33	35	35	32
36	35	35	32
39	35	35	32
42	35	35	32
45	35	35	32
48	35	35	32
51	36	35	33
54	36	35	36
57	36	36	37
60	37	38	38
63	38	39	39
66	39	40	39
69	40	42	40
72	40	42	41
75	40	43	42
78	42	44	42
81	42	44	43
84	42	45	43
87	42	45	44
90	42	45	44
93	42	46	44
96	42	46	45
99	42	46	45
102	42	46	44
105	42	46	44
108	42	46	44
111	42	46	45
114	42	46	45
117	42	46	45
120	42	46	44
123	42	46	44
126	42	46	44
129	42	46	44
132	43	47	44
135	43	47	44
138	43	46	44
141	43	46	43
144	43	47	43
147	44	46	42
150	44	46	42
153	43	46	41
156	43	46	41
159	43	46	40
162	42	46	40
165	43	46	39
168	42	45	39
171	42	45	39
174	42	45	39
177	42	45	38
180	42	45	38
183	42	44	38
186	42	44	38
189	41	44	38
192	41	43	37

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 51 seconds after fire ignition.
3. The thermocouples were attached inside the coat midway down the front of the upper arm.
4. The chest thermocouple was used for external temperature reference.

Table 13. Burn 1 Leg Temperature Data.

Time (sec)	Lft Thigh (°C)	Rt Thigh (°C)	Ext Chest (°C)
0	32	34	32
3	32	34	32
6	32	34	32
9	32	33	32
12	32	33	31
15	32	33	32
18	32	33	32
21	32	33	32
24	32	33	32
27	32	33	32
30	32	33	32
33	32	33	32
36	32	33	32
39	32	33	32
42	32	34	32
45	32	34	32
48	32	34	32
51	32	34	33
54	32	34	36
57	33	34	37
60	33	35	38
63	33	35	39
66	34	35	39
69	34	36	40
72	34	36	41
75	35	36	42
78	35	36	42
81	35	36	43
84	36	37	43
87	36	37	44
90	36	37	44
93	36	37	44
96	37	37	45
99	37	37	45
102	37	38	44
105	37	38	44
108	38	38	44
111	38	38	45
114	38	38	45
117	39	38	45
120	39	38	44
123	39	38	44
126	39	38	44
129	39	38	44
132	39	38	44
135	39	38	44
138	39	38	44
141	38	38	43
144	38	38	43
147	38	38	42
150	38	38	42
153	38	38	41
156	38	37	41
159	38	37	40
162	37	37	40
165	37	37	39
168	37	37	39
171	37	37	39
174	37	37	39
177	37	36	38
180	36	36	38
183	36	36	38
186	36	36	38
189	36	36	38
192	36	36	37

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 51 seconds after fire ignition.
3. The thermocouples were attached inside the Janesville pants near the upper front thigh.
4. The chest thermocouple was used for external temperature reference.

Table 14. Burn 2 Hood Temperature Data.

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
0	38	34	33
3	38	34	32
6	38	34	33
9	38	34	33
12	38	34	33
15	38	34	33
18	38	34	33
21	38	34	33
24	38	34	32
27	38	34	33
30	38	34	33
33	38	34	33
36	38	34	33
39	38	34	33
42	38	34	33
45	38	34	33
48	38	34	33
51	38	34	33
54	38	34	33
57	38	34	33
60	38	34	33
63	38	34	33
66	38	34	33
69	38	34	33
72	38	34	33
75	38	34	33
78	38	34	34
81	38	34	34
84	38	35	34
87	38	36	35
90	39	38	35
93	39	41	40
96	39	47	47

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
99	40	52	51
102	40	58	53
105	41	61	53
108	42	62	53
111	43	64	55
114	44	65	56
117	44	66	53
120	45	64	49
123	44	62	52
126	45	62	54
129	45	64	54
132	45	64	51
135	45	63	51
138	45	66	52
141	45	66	52
144	45	66	52
147	45	65	51
150	45	64	50
153	46	63	50
156	46	62	49
159	45	59	48
162	45	57	47
165	45	55	46
168	45	54	46
171	44	53	45
174	44	51	45
177	44	50	45
180	44	49	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 87 seconds after fire ignition.
3. The thermocouples were on the Nomex hood exterior and covered by the helmet/flaps.
4. The chest thermocouple was used for external temperature reference.

Table 15. Burn 2 Arm Temperature Data.

Time (sec)	Rt Arm (oC)	Lft Arm (oC)	Ext Chest (oC)
0	36	36	33
3	36	36	32
6	36	36	33
9	36	36	33
12	36	36	33
15	36	36	33
18	36	36	33
21	36	36	33
24	36	36	32
27	36	36	33
30	36	36	33
33	36	36	33
36	36	36	33
39	36	36	33
42	36	36	33
45	36	36	33
48	36	36	33
51	36	36	33
54	36	36	33
57	36	36	33
60	36	36	33
63	36	36	33
66	36	36	33
69	36	36	33
72	36	36	33
75	36	36	33
78	36	36	34
81	36	36	34
84	36	36	34
87	36	36	35
90	36	36	35
93	36	37	40
96	37	37	47
99	38	39	51
102	39	41	53
105	40	43	53
108	42	45	53
111	43	47	55
114	44	48	56
117	43	48	53
120	42	49	49
123	42	49	52
126	42	49	54
129	43	50	54
132	44	50	51
135	44	50	51
138	45	50	52
141	45	50	52
144	46	50	52
147	46	50	51
150	46	49	50
153	44	49	50
156	45	49	49
159	44	48	48
162	44	48	47
165	44	48	46
168	43	48	46
171	43	48	45
174	43	48	45
177	43	47	45
180	43	47	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 87 seconds after fire ignition.
3. The thermocouples were attached inside the coat midway down the front of the upper arm.
4. The chest thermocouple was used for external temperature reference.

Table 16. Burn 2 Leg Temperature Data.

Time (sec)	Lft Thigh (°C)	Rt Thigh (°C)	Ext Chest (°C)
0	33	32	33
3	33	32	32
6	33	32	33
9	34	33	33
12	34	32	33
15	34	32	33
18	33	32	33
21	33	32	33
24	33	32	32
27	33	32	33
30	33	32	33
33	33	32	33
36	33	33	33
39	33	33	33
42	33	32	33
45	33	33	33
48	33	33	33
51	33	33	33
54	33	33	33
57	33	33	33
60	33	34	33
63	32	34	33
66	32	34	33
69	32	34	33
72	32	34	33
75	32	34	33
78	32	34	34
81	32	34	34
84	33	35	34
87	33	35	35
90	33	35	35
93	33	35	40
96	33	35	47
99	34	35	51
102	34	36	53
105	35	36	53
108	35	37	53
111	36	37	55
114	36	37	56
117	36	37	53
120	37	37	49
123	37	37	52
126	37	38	54
129	38	38	54
132	38	38	51
135	38	38	51
138	39	38	52
141	39	39	52
144	39	39	52
147	39	39	51
150	39	39	50
153	39	39	50
156	39	39	49
159	39	39	48
162	39	39	47
165	39	39	46
168	38	38	46
171	38	38	45
174	38	38	45
177	38	38	45
180	37	38	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 87 seconds after fire ignition.
3. The thermocouples were attached inside the Janesville pants near the upper front thigh.
4. The chest thermocouple was used for external temperature reference.

Table 17. Burn 3 Hood Temperature Data.

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
0	38	37	33
3	38	37	33
6	38	37	33
9	38	37	33
12	38	37	33
15	38	37	33
18	38	38	33
21	38	37	33
24	38	38	33
27	38	38	33
30	38	38	33
33	38	38	33
36	38	38	34
39	38	38	34
42	38	38	34
45	38	38	34
48	38	38	34
51	38	38	33
54	38	38	33
57	38	38	34
60	38	38	34
63	38	38	35
66	38	38	36
69	38	39	37
72	38	39	37
75	38	39	38
78	38	40	39
81	38	41	39
84	38	42	40
87	38	44	42
90	38	47	46
93	39	52	47
96	39	57	49
99	39	58	49
102	39	58	49
105	40	58	50
108	40	59	50
111	40	59	51
114	40	57	53
117	40	56	54
120	40	57	54
123	41	57	54
126	41	57	54
129	41	58	53
132	41	59	53
135	41	58	52
138	41	58	52
141	41	58	51
144	41	58	51
147	41	58	50
150	41	58	49
153	41	57	48
156	41	56	47
159	41	55	47
162	41	54	46
165	41	53	45

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 60 seconds after fire ignition.
3. The thermocouples were on the Nomex hood exterior and covered by the helmet/flaps.
4. The chest thermocouple was used for external temperature reference.

Table 18. Burn 3 Arm Temperature Data.

Time (sec)	Rt Arm (°C)	Lft Arm (°C)	Ext Chest (°C)
0	37	36	33
3	37	36	33
6	37	36	33
9	37	36	33
12	37	36	33
15	37	36	33
18	37	36	33
21	37	36	33
24	37	36	33
27	37	36	33
30	37	36	33
33	37	36	33
36	37	36	34
39	37	36	34
42	37	36	34
45	37	36	34
48	37	36	34
51	37	36	33
54	37	36	33
57	37	36	34
60	37	36	34
63	37	36	35
66	37	37	36
69	37	37	37
72	37	37	37
75	37	38	38
78	37	38	39
81	38	39	39
84	38	39	40
87	39	39	42
90	40	40	46
93	41	42	47
96	42	43	49
99	43	44	49
102	45	45	49
105	46	46	50
108	47	46	50
111	48	46	51
114	49	47	53
117	51	48	54
120	54	49	54
123	56	50	54
126	57	50	54
129	57	51	53
132	57	51	53
135	57	51	52
138	56	51	52
141	56	51	51
144	54	51	51
147	54	51	50
150	53	51	49
153	52	51	48
156	52	50	47
159	51	50	47
162	51	50	46
165	50	50	45

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 60 seconds after fire ignition.
3. The thermocouples were attached inside the coat midway down the front of the upper arm.
4. The chest thermocouple was used for external temperature reference.

Table 19. Burn 3 Leg Temperature Data.

Time (sec)	Lft Thigh (°C)	Rt Thigh (°C)	Ext Chest (°C)
0	34	34	33
3	34	34	33
6	34	34	33
9	33	34	33
12	33	34	33
15	33	34	33
18	33	34	33
21	33	34	33
24	33	34	33
27	33	34	33
30	33	34	33
33	33	34	33
36	33	34	34
39	33	34	34
42	33	34	34
45	33	34	34
48	33	34	34
51	33	34	33
54	33	33	33
57	33	33	34
60	33	34	34
63	33	34	35
66	33	34	36
69	34	35	37
72	34	35	37
75	34	35	38
78	34	35	39
81	34	35	39
84	35	35	40
87	35	36	42
90	35	36	46
93	36	36	47
96	36	36	49

Time (sec)	Lft Thigh (°C)	Rt Thigh (°C)	Ext Chest (°C)
99	37	37	49
102	38	37	49
105	38	38	50
108	39	38	50
111	39	39	51
114	40	39	53
117	40	39	54
120	42	40	54
123	43	41	54
126	44	41	54
129	44	41	53
132	45	41	53
135	45	41	52
138	45	41	52
141	44	41	51
144	44	40	51
147	43	40	50
150	43	40	49
153	42	40	48
156	42	40	47
159	41	40	47
162	41	40	46
165	40	39	45

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 60 seconds after fire ignition.
3. The thermocouples were attached inside the Janesville pants near the upper front thigh.
4. The chest thermocouple was used for external temperature reference.

Table 20. Burn 4 Hood Temperature Data.

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
0	37	37	35
3	37	37	35
6	37	37	35
9	37	37	35
12	37	37	35
15	38	37	35
18	37	37	35
21	38	37	35
24	38	37	35
27	38	37	35
30	38	37	35
33	37	37	35
36	37	37	35
39	37	37	35
42	37	37	35
45	37	36	35
48	37	36	35
51	37	36	36
54	37	37	40
57	37	37	43
60	38	39	51
63	38	41	50
66	38	42	49
69	38	43	50
72	38	43	50
75	38	42	51
78	38	42	51
81	38	42	50
84	38	42	50
87	38	42	50
90	38	42	50
93	38	42	49
96	38	43	49

Time (sec)	Head (°C)	Ear (°C)	Ext Chest (°C)
99	38	43	49
102	38	43	49
105	38	43	48
108	38	43	48
111	38	43	48
114	39	43	48
117	39	43	47
120	39	43	47
123	39	43	47
126	39	43	47
129	39	43	46
132	39	43	46
135	39	43	46
138	38	43	46
141	39	43	46
144	39	43	45
147	39	43	45
150	39	43	45
153	39	43	45
156	39	43	45
159	39	43	45
162	39	43	45
165	39	43	44
168	39	43	44
171	39	43	44
174	39	43	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.
3. The thermocouples were on the Nomex hood exterior and covered by the helmet/flaps.
4. The chest thermocouple was used for external temperature reference.

Table 21. Burn 4 Arm Temperature Data.

Time (sec)	Rt Arm (°C)	Lft Arm (°C)	Ext Chest (°C)
0	37	37	35
3	37	37	35
6	37	37	35
9	37	37	35
12	37	37	35
15	37	37	35
18	37	37	35
21	37	37	35
24	37	37	35
27	37	37	35
30	37	37	35
33	37	37	35
36	37	37	35
39	37	37	35
42	37	37	35
45	37	37	35
48	37	37	35
51	37	37	36
54	37	37	40
57	37	37	43
60	37	38	51
63	37	38	50
66	37	38	49
69	38	39	50
72	38	39	50
75	38	40	51
78	38	40	51
81	39	41	50
84	39	41	50
87	39	41	50
90	39	41	50
93	39	42	49
96	39	42	49

Time (sec)	Rt Arm (°C)	Lft Arm (°C)	Ext Chest (°C)
99	39	42	49
102	39	42	49
105	39	42	48
108	40	43	48
111	40	43	48
114	40	43	48
117	40	43	47
120	41	43	47
123	41	43	47
126	41	43	47
129	41	43	46
132	41	43	46
135	41	43	46
138	41	43	46
141	41	43	46
144	41	43	45
147	41	44	45
150	41	44	45
153	41	44	45
156	41	44	45
159	41	44	45
162	42	44	45
165	41	43	44
168	41	43	44
171	41	43	44
174	41	43	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.
3. The thermocouples were attached inside the coat midway down the front of the upper arm.
4. The chest thermocouple was used for external temperature reference.

Table 22. Burn 4 Leg Temperature Data.

Time (sec)	Lft Thigh (°C)	Rt Thigh (°C)	Ext Chest (°C)
0	35	36	35
3	35	36	35
6	35	36	35
9	35	36	35
12	35	36	35
15	35	36	35
18	35	36	35
21	35	36	35
24	35	36	35
27	35	36	35
30	35	36	35
33	35	36	35
36	35	36	35
39	35	35	35
42	35	35	35
45	35	35	35
48	35	36	35
51	35	36	36
54	35	36	40
57	36	36	43
60	36	36	51
63	36	37	50
66	37	37	49
69	37	38	50
72	38	38	50
75	38	39	51
78	38	39	51
81	38	40	50
84	39	40	50
87	39	40	50
90	39	40	50
93	39	40	49
96	39	40	49
99	40	40	49
102	40	40	49
105	40	40	48
108	40	40	48
111	40	40	48
114	40	40	48
117	40	40	47
120	40	40	47
123	40	40	47
126	40	39	47
129	40	39	46
132	41	39	46
135	41	39	46
138	41	39	46
141	41	39	46
144	41	39	45
147	41	40	45
150	41	40	45
153	41	40	45
156	40	40	45
159	40	40	45
162	40	40	45
165	40	40	44
168	40	40	44
171	40	40	44
174	40	40	44

Notes:
1. Time represents fire ignition to firefighter exit from the house.
2. The house was entered 36 seconds after fire ignition.
3. The thermocouples were attached inside the Janesville pants near the upper front thigh.
4. The chest thermocouple was used for external temperature reference.

Table 23. Bunker Gear Temperature Changes.

	Enter House to Peak	Quickest Temp Change	Sustained Temp
Burn 1			
Left Arm	35 to 47°C in 81 sec	40 to 42°C in 3 sec	46±1°C for 96 sec
Right Arm	36 to 44°C in 96 sec	37 to 40°C in 9 sec	43±1°C for 108 sec
Lf Thigh	32 to 39°C in 66 sec	33 to 36°C in 27 sec	38±1°C for 81 sec
Rt Thigh	34 to 38°C in 51 sec	35 to 36°C in 9 sec	38±1°C for 90 sec
Ext Chest	33 to 45°C in 45 sec	33 to 36°C in 3 sec	44±1°C for 63 sec
Burn 2			
Left Arm	36 to 50°C in 42 sec	39 to 48°C in 15 sec	49±1°C for 60 sec
Right Arm	36 to 46°C in 57 sec	40 to 42°C in 3 sec	45±1°C for 33 sec
Lf Thigh	33 to 39°C in 51 sec	34 to 36°C in 12 sec	38±1°C for 60 sec
Rt Thigh	35 to 39°C in 54 sec	36 to 37°C in 6 sec	38±1°C for 72 sec
Ext Chest	35 to 56°C in 27 sec	40 to 47°C in 3 sec	51±1°C for 21 sec
Burn 3			
Left Arm	36 to 51°C in 69 sec	40 to 42°C in 3 sec	50±1°C for 45 sec
Right Arm	37 to 57°C in 66 sec	43 to 45°C in 3 sec	38±1°C for 27 sec
Lt Thigh	33 to 45°C in 42 sec	40 to 42°C in 6 sec	44±1°C for 27 sec
Rt Thigh	34 to 41°C in 63 sec	40 to 41°C in 3 sec	40±1°C for 54 sec
Ext Chest	34 to 54°C in 57 sec	42 to 46°C in 3 sec	53±1°C for 24 sec
Burn 4			
Left Arm	37 to 44°C in 111 sec	39 to 41°C in 12 sec	43±1°C for 81 sec
Right Arm	37 to 42°C in 126 sec	40 to 41°C in 12 sec	40±1°C for 93 sec
Lt Thigh	35 to 41°C in 96 sec	37 to 38°C in 6 sec	40±1°C for 99 sec
Rt Thigh	36 to 40°C in 45 sec	37 to 40°C in 18 sec	39±1°C for 105 sec
Ext Chest	35 to 51°C in 24 sec	43 to 51°C in 3 sec	46±1°C for 45 sec

Notes:

1. Burns 2 and 3 were fully involved fires.
2. The Burn 2 test firefighter did not proceed past tracking point 4 before team retreat.
3. Burns 3 and 4 used positive pressure ventilation.
4. External Chest data are for outside temperature comparison only.

Table 24. Bunker Gear Temperature Rates.

	Enter House to Peak (°C/second)	Quickest Temp Change (°C/second)
Burn 1		
Left Arm	0.15	0.67
Right Arm	0.08	0.33
Lf Thigh	0.11	0.11
Rt Thigh	0.08	0.11
Ext Chest	0.27	1.00
Burn 2		
Left Arm	0.33	0.60
Right Arm	0.18	0.67
Lf Thigh	0.12	0.17
Rt Thigh	0.07	0.33
Ext Chest	0.78	2.33
Burn 3		
Left Arm	0.22	0.67
Right Arm	0.30	0.67
Lt Thigh	0.17	0.33
Rt Thigh	0.11	0.33
Ext Chest	0.35	1.33
Burn 4		
Left Arm	0.06	0.17
Right Arm	0.04	0.08
Lt Thigh	0.06	0.17
Rt Thigh	0.09	0.17
Ext Chest	0.67	2.67

Note:
1. Rate calculations are based on values in Table 23.

ENCLOSURE 1

Janesville Master Specifications

from

Lion Apparel

Note

An "*" marks the materials used in the firefighter's bunker gear.

November, 1993

JANESVILLE

MASTER SPECIFICATIONS

COMMANDO

TURNOUT COAT

SCOPE: This protective clothing is for conventional structural fire fighting only to protect the body, excluding head, hands, and feet against temperature extremes, steam, hot water, hot particles and other hazards encountered during fires and related emergencies. This protective clothing is not proximity or entry gear, and is not designed to be kept in direct contact with flames.

NFPA 1971: All construction, features, and fabrics in this specification must meet or exceed the requirements of NFPA Specification 1971, 1991 edition, OSHA 1910, Subpart L, and Cal-OSHA title 8, Article 10.1, Para 3406. Such features, fabrics, construction, trim, and other details, whether specifically enumerated in this specification or not, are the responsibility of the dealer, agent, manufacturer or other seller. Implied or direct conflicts between this specification and NFPA 1971, OSHA, Subpart L, and Cal-OSHA are not the intention of this specification, and will be eliminated by notifying the issuing authority and subsequent alteration of the specification.

COAT LENGTH: When measured at the center of the back from the collar seam to the hem bottom, the coat shall measure either 29" or 32" long.

** **OUTER SHELL MATERIAL:** The Outer Shell shall be 100% Nomex®III of plain weave, and weigh approximately 7.5 oz. per square yard with water repellent finish. Color to be (Black, Natural, Yellow, Lime-Yellow, Tan, Red).

OUTER SHELL MATERIAL: The Outer Shell shall be 60% Kevlar®, 40% PBI® rip stop weave, and weigh approximately 7.5 oz per square yard with a water repellent finish. Color to be (Natural (PBI® Gold), Black).

OUTER SHELL MATERIAL: The Outer Shell shall be 60% Kevlar®, 40% PBI®, rip-stop weave, and weigh approximately 6.0 oz. per square yard with water repellent finish. Color to be Natural (PBI® lightweight Gold).

OUTER SHELL MATERIAL: The Outer Shell material shall be 60% Kevlar®/40% Nomex®III, and weigh approximately 7.0 oz. per square yard with a water repellent finish. Color to be Yellow, Black, Tan, or Rust.

THERMAL LINER MATERIAL: Thermal Liner shall be quilted composed of 100% dyed Nomex® pajama check face cloth quilted to 100% reprocessed (recycled) aramid batting, and weighing approximately 8.5 oz. per square yard. This material shall meet the requirements of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be quilting composed of 100% dyed Nomex® pajama check face cloth quilted to three layers of spunlaced SL/E89 aramid material of 85% Nomex® and 15% Kevlar®, and weighing approximately 7.5 oz. per square yard. These materials shall meet the requirements of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be quilted composed of 100% dyed Nomex® pajama check face cloth quilted to 70% reproccessed Kevlar®/30% Virgin Kevlar® batting, and weighing approximately 7.05 oz. per square yard. This material shall meet the requirements of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be "ARAFLO" composed of 100% Nomex® III face cloth quilted to three layers of apertured spunlaced SL/E89 aramid material with 11-13 apertures per sq. inch, and weighing 7.5 oz per square yard. These materials shall meet the requirements of NFPA Standard 1971.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 50/50% Polyester/Cotton plain weave with an application of fire resistant neoprene. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 100% Nomex® pajama check with an application of fire resistant neoprene. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 100% Nomex® pajama check rip-stop laminated to a lightweight film of breathable Teflon, "Gore-Tex" membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be SL/E-89 spunlaced Nomex® aramid material of 85% Nomex® and 15% Kevlar® laminated to a lightweight film of breathable Teflon, "Gore-Tex®" membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be SL/E-89 spunlaced Nomex® aramid material of 85% Nomex® and 15% Kevlar® laminated to a lightweight film of breathable Teflon, "Tetratex®" membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

CONSTRUCTION DETAILS: The coat is designed with a 3 panel construction in all layers to provide a proper fit.

THREAD: All thread to be Nomex, and of a minimum of 7-8 stitches per inch.

STITCHING: All stitching conforms to Federal Standard 751 Specifications (FED-STD-751).

RIVETING: All Outer Shell stress points, including top and bottom pocket corners, pocket flap corners, top and bottom of storm flap, harness snaps and Dee rings shall be riveted using two (2) piece, plated steel rivets, backed with split cowhide leather washers not less than 1" in diameter for additional strength.

METAL CONTACT PREVENTION: The coat is to be constructed such that when completely assembled there shall be no direct metal contact from the exterior of the Outer Shell through the Thermal Liner to the wearer's body. This is intended to prevent a pathway for the conduction of heat to the skin, and shall apply to the use of all rivets, snaps, hooks, dees, zippers or any other metal used to fabricate the coat.

COMBINATION MOISTURE BARRIER/THERMAL LINER ASSEMBLY: The combination Moisture Barrier/Thermal Liner shall be designed to be compatible with the Outer Shell so it does not buckle, pull, or otherwise restrict body motion, even when the arms are raised.

The left and right fronts of the Thermal Liner-Moisture Barrier shall be attached to facings on the fronts of the Outer Shell. The neck of the Thermal Liner-Moisture Barrier shall be secured the neck of the Outer Shell collar such that when donning the coat an arm may not be accidentally caught between the Outer Shell and its inner linings along the neck between the armholes.

A fire retardant neoprene coated polyester/cotton moisture barrier material shall be sewn approximately 3" from sleeve ends to the moisture barrier to form a waterwell. The waterwell is attached to the outer shell cuff.

(Neoprene) The Moisture Barrier shall be completely sewn to the Thermal Liner at its perimeter with the Neoprene side facing outward from the Thermal Liner. All edges are to be sewn together and bound with non-wicking Moisture Barrier material. All moisture barrier seams are to be sealed as required by the NFPA 1971, 1991 Edition. The Moisture Barrier/Thermal Liner shall be no more than three (3) inches from the coat hem.

(Breathable) The Moisture Barrier shall be completely sewn to the Thermal Liner at its perimeter with the Teflon facing toward the Thermal Liner. All edges are to be sewn together and bound with non-wicking Moisture Barrier material. All Moisture Barrier seams are to be sealed with Gore-Tex® Seam Tape to prevent leakage. The Moisture Barrier/Thermal Liner Shall be no more than two (2) inches from the coat hem.

The combination Thermal Liner-Moisture Barrier shall include an

inside 6" x 6" set-on pocket with serge seam reinforced pocket edges.

MOISTURE BARRIER/THERMAL LINER ATTACHMENT:

a) MISSING LINER INDICATION SYSTEM: The missing liner indicator system shall identify whether or not the fire fighter is wearing all components of protective coat. The missing liner indicator shall be a split collar system.

The outer most layer of the collar shall be outer shell material with moisture barrier material stitched at the edges and both sewn to the outer shell of the coat at the neck area. The outer most layer shall have VELCRO fastener hook sewn on the inside facing the neck 3/4" wide across contoured top, and 2" wide along each end.

The inner most layer facing the wearer's body shall be outer shell material with moisture barrier material stitched at the edges and both sewn and seam sealed to the thermal/moisture barrier at the neck area. Seam sealing shall assure waterproofness at the neck area. The inner most layer shall have VELCRO fastener pile sewn on the inside facing the neck 3/4" wide across contoured top, and 2" wide along each end, such that inner most layer and outer most layer shall line up and be secured by VELCRO fastener.

The Moisture Barrier/Thermal Liner shall be completely detachable from the Outer Shell for ease of cleaning, but identifiable as missing liner system. Attachment shall be by means of VELCRO fastener at collar/neck area. There shall be four (4) snaps, each composed of a plated steel cap, socket, post, and stud, on each front facing, and one (1) snap on each sleeve end.

When the liner is removed, the white moisture barrier material becomes visible, as well as the VELCRO fastener hook stitched to the outer most layer will cause irritation to the neck of the wearer.

b) COMPLETELY REMOVABLE: The Moisture Barrier/Thermal Liner shall be completely detachable from the Outer Shell for ease of cleaning by using not less than twelve (12) snaps - each composed of a plated steel cap, socket, post, and stud. There shall be three (3) snaps on each front facing, four (4) snaps on the neck facing, three (3) 4" x 1" Velcro (Hook & Pile) strips evenly spaced along Nomex® neck facing, and one (1) snap on each sleeve end.

c) PERMANENTLY ATTACHED: The Moisture Barrier/Thermal Liner shall be permanently attached by using three (3) bartacks at the Nomex® neck facing. At other than the neck area, attachment shall be by means of not less than eight (8) snaps - each composed of a plated steel cap, socket, post, and stud. There shall be three (3) snaps on each front facing, and one (1) snap on each sleeve end.

OUTER SHELL COLLAR: Collar to be of four (4) layer configuration

such that when the collar is raised it will remain standing and provide continuous thermal and moisture protection around the neck and face. To ensure this protection the inside of the collar shall be fully lined with moisture barrier and thermal liner material.

Every component of this collar shall meet or exceed NFPA 1971. The outer-most layer of the collar shall be Outer Shell material. Moisture Barrier and Thermal Liner shall be the composite inner layer and shall face such that the neoprene side be next to the outer most layer. The inner-most layer facing the wearer's body shall be outer shell fabric to meet NFPA 1971. The collar shall be assembled using stitch 401 turned and topstitched using stitch 301, seam Ssc-1, 8 S.P.I. The collar is to be of contour style, not less than 5" high in the front and no less than 4" high in the back.

When examined prior to donning, the turned-up collar shall completely wrap around the front of the neck opening such that left and right collars touch or overlap to maximize facial protection.

COLLAR HANGER LOOP: A fabric hanger loop of NFPA 1971 approved fabric shall be provided inside the neck at the collar. It shall be designed to provide long service and shall not tear or separate from the coat when coat is hung by the hanger loop, loaded evenly with a weight of 80 pounds and allowed to hang for one minute.

OUTER SHELL THROAT STRAP: The frontal throat strap shall be mounted to the Outer Shell collar to ensure that, when the coat is closed and the collar is raised, the throat strap shall prevent any opening between the left and right collars, and shall overlap the left and right coat fronts below the collar. For additional protection against steam penetration, the frontal throat strap shall be formed by two layers of Outer Shell material and a layer of NFPA approved moisture barrier and thermal liner material positioned between the two layers. The throat strap shall be not less than 9" long and 3" wide, shaped to be compatible with S.C.B.A. face mask, and secured in the stowed position with a 1½" x 3" hook fastener tape on the left outside of the collar. A 1½" x 3" piece of hook fastener tape shall be sewn to the end of the throat strap. A corresponding 3" x 3" piece of pile fastener tape shall be sewn to the outer shell material of the right side of the collar to provide maximum adjustment when wearing a breathing apparatus mask.

OUTER SHELL THERMAL FRONT PANEL CONSTRUCTION: There shall be continuous thermal and moisture protection around the entire torso including the coat front area beneath the storm flap. To ensure this protection, both right and left inside front facings of the coat Outer Shell shall incorporate an additional layer of Gore-Tex® on E/89 material along the entire length from collar to hem.

These panels shall be sewn to the left and right coat front leading edges using stitch 401, seam Ssbc-2, inverted 8 S.P.I. 301 stitch, double needles to be set 3/4" apart such that the entire

coat front is stiffened. Every component of this thermal and moisture gap elimination system shall meet or exceed NFPA 1971.

BELLOWS UNDERARM CONSTRUCTION: Bellows underarm construction shall be used on all layers of the coat--its Outer Shell, Moisture Barrier, and Thermal Liner--to ensure maximum upper body freedom of movement including complete arm mobility when reaching up and/or forward. Bellows construction is extended to all inner layers of the coat to make it possible for the fit and freedom of movement, derived from the Outer Shell bellows construction, to be passed through the inner layers to the wearer's body.

The Outer Shell, Moisture Barrier, and Thermal Liner bellows shoulder construction shall consist of an underarm and shoulder bellows of elongated football shape not less than 8" wide by not less than 15" long sewn into each of the coats fabric layers by two needle construction. The bellows in each layer shall begin at a point corresponding to the front of the armpit, wrap around under the arm and shoulder joint, and terminate at the rear top of the shoulder.

THERMAL ENHANCED BACK YOKE: There shall be an additional layer of spunlaced SL/E89 aramid material of 85% Nomex® and 15% Kevlar®, and weighing 2.7 oz. per square yard added to the inner layer between the moisture barrier and thermal liner. This added layer of aramid material shall be sewn to the inside of the upper back portion of the thermal liner of the coat. This additional layer shall be across the upper back from the back shoulder and collar seams 7" down and across the back ending at the armhole. The additional layer will provide extra thermal protection in a high heat and compression area of the coat.

OUTER SHELL SLEEVE WELL AND WRISTLET MOUNTING: A moisture barrier leader of 5" in length shall be sewn 3" back from the combination liner sleeve end to form the sleeve well. This sleeve well shall prevent water and hazardous materials from entering the sleeve when arms are in the raised position. The moisture barrier leader shall be constructed of fire resistant neoprene coated cotton/polyester, oriented with the coating toward the outside. A 1" wide strip of Velcro pile shall be sewn full circumference to the end of the moisture barrier leader to help secure the combination liner to sleeve cuffs. For added safety, 1 male snap fastener shall be set in the Velcro pile to assist in attaching combination liner to outer shell.

An inner internal wristlet shall consist of a 2-ply over the hand Kevlar®/Spandex, Nomex/Spandex, PBI/Spandex) bank knitted not less than 8" in length for extended thermal and slash protection. The wristlets shall be double stitched and bound to the moisture barrier/thermal liner.
(over the hand add following paragraph)
The wristlets shall extend completely over the palm with a separate thumbhole to prevent the wristlet from sliding back for maximum reliable thermal protection.

The combination liner sleeve ends shall be inserted into the outer shell sleeve ends by means of matching the Velcro pile on the combination liner sleeve end to the Velcro hook on the outer shell sleeve end, and by lining up the snap fasteners. This method of combination liner attachment shall prevent any gaps from occurring between the combination liner and sleeve well during a full range of movements. Combination liner shall extend to within 3" at sleeve end.

OUTER SHELL SLEEVES: The sleeves are to be of full length and of shoulder insert, two-panel type construction assembled using stitch 401, Seam Lsc-2, and set using stitch 515, seam Ssa-2, 9 S.P.I. followed by topstitching for complete reliability.

OUTER SHELL SLEEVE CUFFS: The cuff of the sleeve shall be reinforced with a binding not less than 3" in total width and to be (outer shell fabric, pearl gray split cowhide leather, black split cowhide leather) for abrasion resistance and thermal protection. At least 2" of the cuff reinforcement shall extend down the interior of the outer shell sleeve, and a 1" wide strip of Velcro hook shall be sewn full circumference on the inside of the cuff reinforcement. For added safety, 1 female snap fastener shall be set in the Velcro hook to assist in attaching outer shell to combination liner.

FREEDOM ELBOW: The sleeve shall have an insert which will provide a natural bend to the sleeve. The insert shall be in the back of each sleeve and will be a shortened "football" shape, 6" wide in the middle an 3" wide at the seams. For added thermal protection an additional layer of spunlaced SL/E89 aramid material, of 85% Nomex® and 15% Kevlar® shall be sewn to the inside of the thermal liner. The material shall weigh 2.7 oz. per square yard. The freedom design shall be incorporated into all layers.

The Outer Shell insert shall utilize (pearl gray split cowhide leather, black split cowhide leather, self material) for abrasion resistance and thermal protection.

PADDED ELBOWS: In addition to reinforcement, elbows shall be padded using one layer of neoprene coated nonwoven aramid material. The reinforcement material shall be sandwiched between the Outer Shell and elbow reinforcement. Neoprene shall face outward.

OUTER SHELL SHOULDER REINFORCEMENT: A 6" wide area at the top of the shoulders extending from the shoulder seam to a width of 4" at the collar shall be capped with (pearl gray split cowhide leather, black split cowhide leather, self material) for abrasion resistance and thermal protection.

A) SHOULDER PADS: The shoulders of the coat shall be padded with Impax: Two Impax shock absorbing shoulder pads of rigid fiber plate encased in ensolite foam, 3/8" thick on shoulder side and 3/16" thick on outside. These protective pads shall be secured inside the shoulders of the coat with a strip of VELCRO fastener

which permits individual adjustment. The pads shall be lightweight, waterproof, washable and unbreakable.

B) SHOULDER PADS: Coat shall have two (2) soft shoulder pads made of layered fire retardant neoprene coated nonwoven aramid material, secured to the outer shell with VELCRO fastener. Neoprene coating shall face outward.

COAT FRONT CLOSURE DESIGN: The complete Outer Shell coat front closure design shall consist of a FRONT CLOSURE SYSTEM completely protected by an OUTSIDE STORM FLAP which shall have its own, independent STORM FLAP CLOSURE SYSTEM.

OUTSIDE STORM FLAP: The storm flap shall be set on the outside of the right side of the coat opening for maximum thermal protection and clear drainage. The storm flap shall be not less than 5" wide, nor less than 22" long for 40". (Inside hook and dees coat closure shall utilize 7" wide storm flap)

The storm flap shall be securely sewn using stitch 301, seam SSc-1, turned, and topstitched using stitch 301 seam SSc-2. The storm flap shall then be double needle set, 5/8" gauge, using stitch 301, seam SSb-2, and both the top and bottom of this seam shall be secured by double riveting with split cowhide leather backed plated steel rivets.

OUTER SHELL FRONT CLOSURE SYSTEM:

a) (snaps and hook & dee rings) Not less than four (4) snaps, by which the coat front may be closed, shall be fitted under the storm flap and along the leading edge of the left and right sides of the coat. Each snap shall consist of a plated steel cap, socket, post and stud. The storm flap shall be closed using four (4) standard snap hooks, each securely riveted with three (3) plated steel, leather backed rivets, approximately 5 1/4" back from the leading edge of the left side of the coat to engage Dee rings on the storm flap. The dee rings shall each be securely riveted with two (2) plated steel, leather backed rivets, along the leading outside edge of the storm flap. The snap hooks and dee rings shall be spaced with the first hook at the top of the coat, the second hook 4" from the first, the third hook 5" below the second, and the fourth hook 5" below the third.

b) (velcro and hook & dee rings) 1 1/2" wide strips of VELCRO hook and pile fastener shall be sewn under the storm flap, and along the leading edge of the left and right sides of the coat. This VELCRO fastener shall close the coat front. The storm flap shall be closed using four (4) standard snap hooks, each securely riveted with three (3) plated steel, leather backed rivets, approximately 5 1/4" back from the leading edge of the left side of the coat to engage Dee rings on the storm flap. The dee rings shall each be securely riveted with two (2) plated steel, leather backed rivets, along the leading outside edge of the storm flap. The snap hooks and dee rings shall be spaced with the first hook at the top of the

coat, the second hook 4" from the first, the third hook 5" below the second, and the fourth hook 5" below the third.

c) (zipper and VELCRO) The closure system to be of the Janesville quick-release "E-MERG" type - such that fast closure and exit is possible, yet the coat remains securely closed while the fire fighter is working. This "E-MERG" closure system shall consist of a #7 brass quick-release zipper as an inner closure. The storm flap closure of 1 1/2" VELCRO, with the "hook" portion of the VELCRO closure sewn on the left front of the coat, and the "pile" portion sewn on the inner side of the outer storm flap. The VELCRO fastener shall extend the length of the outer storm flap to the bottom of the "E-MERG" zipper track. The VELCRO storm flap closure shall eliminate all exposed frontal hardware.

d) (hook & dee rings and VELCRO) (requires 7" wide storm flap) On the right side of the coat front underneath the storm flap at its extreme right hand side shall be fitted, three (3) Dee Rings, four (4) Dee Rings using two (2) plated steel, leather backed rivets for each Dee Ring. For each Dee Ring, a standard snap hook shall be fitted with three (3) plated steel rivets to the underside of the left coat front leading edge. Between each snap hook, VELCRO fastener pile shall be mounted to the underside of the left coat front to engage VELCRO fastener hook mounted between the Dee Rings on the right front beneath the storm flap. The storm flap shall be closed with 1 1/2" Hook and Pile VELCRO with the pile portion sewn on the left front of the coat, and the hook portion sewn on the inner side of the storm flap. The Hook and Pile shall extend the length of the storm flap to the bottom most coat front snap fastener.

e) (zipper and hook & dee) The closure system to be of the Janesville quick-release "E-MERG" type - such that fast closure and exit is possible, yet the coat remains securely closed while the fire fighter is working. This "E-MERG" closure system shall consist of a #7 brass quick-release zipper as an inner closure. The storm flap shall be closed using four (4) standard snap hooks, each securely riveted with three (3) plated steel, leather backed rivets, approximately 5 1/4" back from the leading edge of the left side of the coat to engage Dee rings on the storm flap. The dee rings shall each be securely riveted with two (2) plated steel, leather backed rivets, along the leading outside edge of the storm flap. The snap hooks and dee rings shall be spaced with the first hook at the top of the coat, the second hook 4" from the first, the third hook 4" below the second, and the fourth hook 4" below the third.

EXTERNAL ADJUSTMENT DEVICE: One (1) adjustment device shall be affixed to the outside of the coat on each side two (2) inches above hem trim.

Each take-up strap shall comprise of two sub-component straps. The front strap shall be (1) inch wide and (5) inches in length, folded in half to form a loop, and shall be affixed on side of coat by

means of two bartacks spaced (2) inches apart. The loop shall face toward the back and hold a nickel plated 1" tourniquet buckle. The back strap shall be (1) inch wide and (6) inches in length of double thickness outer shell material. The strap shall be affixed to the rear of the back of front body panels by means of two separate bartacks and positioned to allow the loose end to thread through the metal tourniquet buckle. The metal buckle shall allow for adjustment and shall firmly hold the take-up strap in the desired position. Hook and pile (e.g. Velcro) shall be used to secure the loose end of each take-up strap to respective component.

A (1) inch by (4) inch piece of pile fastener tape shall be installed horizontally on each back take-up strap. A (1) inch by (2) inch piece of hook fastener tape shall be installed at the end of the take-up strap and shall be positioned to engage the loop fastener tape.

OUTER SHELL REFLECTIVE TRIM-NFPA STYLE: (Scotchlite, Dual-Trim Scotchlite, Reflexite). Trim color (Red-Orange, Lime-Yellow), to meet the 325 square inch fluorescent retroreflective requirements of NFPA 1971, latest edition, shall be applied as follows: One 3" strip completely around bottom of coat; one 3" strip around each sleeve above cuff area; one 2" band around chest and back area. All trim to be sewn with stitch 301, minimum 6 stitches per inch.

OUTER SHELL REFLECTIVE TRIM-NEW YORK STYLE: (Scotchlite,Reflexite). Trim color (Red-Orange, Lime-Yellow), shall be applied as follows: One 3" strip completely around bottom of coat; one 3" strip around sleeves above cuffs; one 3" strip around sleeves above elbows; one 3" strip completely around chest area approximately the same height as the 3" upper arm trim. All trim to be sewn with stitch 301, minimum 6 stitches per inch.

OUTER SHELL REFLECTIVE TRIM-HIGH VISIBILITY TRIM STYLE: (Scotchlite, Dual-Trim Scotchlite, Reflexite). Trim color (Red-Orange, Lime-Yellow), shall be applied as follows: One 3" strip completely around bottom of coat; one 3" strip around sleeves above cuffs; one 3" strip around sleeves above elbows; one 3" strip completely around chest area approximately the same height as the 3" upper arm trim; two 3" strips vertically on back of coat to form a box with upper back and hem trim. All trim to be sewn with stitch 301, minimum 6 stitches per inch.

OUTER SHELL REFLECTIVE LETTERING: (Scotchlite, Reflexite) letters, color (White, Silver, Red-Orange, Lime-Yellow), in (2",3"), are to be applied as follows:
(Accessory pockets)

1) **OUTER SHELL AIR MASK POCKET, FLAP, AND CLOSURE:** There shall be an air mask pouch made of self material measuring approximately 4" deep, 9 1/2" wide , and 11 1/2" high located on the right chest. Pouch closure shall consist of heavy duty brass zipper mounted on left side of pocket. Drainage of moisture to be provided by eyelets.

2) OUTER SHELL SPECIAL PURPOSE BELLOWS POCKETS, FLAPS, AND CLOSURES: There shall be a flashlight pocket located (right chest, left chest, right sleeve, left sleeve).

This pocket shall be full bellows construction sized 3" wide, 9" deep and expanding by means of side and front gussets to a thickness of 2" in front and back.

The pocket shall be set with double needle Stitch 301, Seam SSb-2 with the top and bottom pocket corners reinforced with plated steel rivets backed with split cowhide leather for additional strength. Drainage of moisture to be provided by eyelets.

Inside the pocket shall be fully lined with neoprene coated polyester/cotton to provide moisture protection to contents of pocket.

Pocket flaps shall be a full 1/2" wider than the width of the pocket on each side, and have a total height equal to the thickness of the pockets bottom gusset plus 3". The flaps shall be formed using Stitch 301, Seam SSa-1, turned, and topstitched using Stitch 301, Seam SSc-2. They shall be set using Stitch 301, Seam SSn-2, inverted and reinforced at each top corner with one (1) plated steel, split cowhide leather reinforced rivet.
(Pocket closure)

a) The pocket flaps shall close to the pocket top with two (2) snaps on each flap arranged such that the flap can easily be grasped by a gloved hand. Snaps shall consist of a plated steel cap, socket, post, and stud.

b) Hook and Pile VELCRO closure system mounted such that the pile is on the pocket and the hook is on the underside of the flap.

3) OUTER SHELL SPECIAL PURPOSE BELLOWS POCKETS, FLAPS, AND CLOSURES: There shall be a radio pocket located (right chest, left chest, right sleeve, left sleeve).

This pocket shall be full bellows construction sized 3 1/2" wide, 9" deep and expanding by means of side and front gussets to a thickness of 2" in front and back.

The pocket shall be set with double needle Stitch 301, Seam SSb-2 with the top and bottom pocket corners reinforced with plated steel rivets backed with split cowhide leather for additional strength. Drainage of moisture to be provided by eyelets.

Inside the pocket shall be fully lined with neoprene coated polyester/cotton to provide moisture protection to contents of pocket.

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b) Hook and Pile VELCRO closure system mounted such that the pile is on the pocket and the hook is on the underside of the flap.

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Inside the pocket shall be fully lined with neoprene coated polyester/cotton to provide moisture protection to contents of pocket.

Pocket flaps shall be a full 1/2" wider than the width of the pocket on each side, and have a total height equal to the thickness of the pockets bottom gusset plus 3". The flaps shall be formed steel, split cowhide leather reinforced rivet.
(Pocket closure)
a) The pocket flaps shall close to the pocket top with two (2) snaps on each flap arranged such that the flap can easily be grasped by a gloved hand. Snaps shall consist of a plated steel cap, socket, post, and stud.

b) Hook and Pile VELCRO closure system mounted such that the pile is on the pocket and the hook is on the underside of the flap.

4) **OUTER SHELL SPECIAL PURPOSE POCKET:** There shall be a spanner wrench pocket located behind (right coat pocket, left coat pocket). This pocket shall be sized 4 1/2" wide and 10" deep.

The pocket shall be set with double needle Stitch 301, Seam SSb-2 with the top and bottom pocket corners reinforced with plated steel rivets backed with split cowhide leather for additional strength. Drainage of moisture to be provided by eyelets.
(Pocket reinforcement)
a) The pocket shall be reinforced with pearl gray split cowhide leather which extends down the bottom 5" of the outside of the pocket.

b) The pocket shall be reinforced with black split cowhide leather which extends down the bottom 5" of the outside of the pocket.

c) The pocket shall be reinforced with self material which extends down the bottom 5" of the outside of the pocket.

5) **FLASHLIGHT HOLDER HOOK AND STRAP:** There shall be a flashlight snap and holder located on (right chest, left chest)

6) **UNIVERSAL STRAP:** There shall be a strap to accomodate a personal alert device with a clip holder, or flashlight equipped with a clip holder. The strap shall be self material 2 1/4" wide and 4" long. Each end of the strap shall be attached to the outer shell with bartacks. Strap shall be located on (left chest, right chest).

7) **OUTER SHELL HANDWARMER POCKETS:** The coat is to have two large outside handwarmer pockets 8" wide and 8" deep set with double needle stitch 301, seam SSb-2 with top pocket opening reinforced with plated steel rivets backed by split cowhide leather for additional strength. Drainage of moisture to be provided by eyelets at each bottom corner. Pockets to be set at bottom of coat hem with reflective trim sewn over pocket.

Pocket shall have 6" diagonal opening cut at upper rear portion. Pocket shall be insulated on the inside with Nomex® Quilt and neoprene coated Polyester/Cotton.

The pocket flaps shall extend 1" over each side of pocket and 2" deep. They shall be formed using stitch 401, seam SSa-1, turned, and topstitched using stitch 301, seam SSn-2, inverted, and reinforced at each top corner with one plated steel rivet reinforced with split cowhide leather. Hook and Pile VELCRO closure system 1" wide x 2" long shall be mounted such that the pile is on the pocket and the hook is on the underside of the flap.

CHEST SIZING: The coat shall be made available in even chest sizes: 34-60, and sleeve lengths Short, Regular, and Long.

LABELING-REQUIREMENTS: The garment shall be labeled in accordance of the requirements of NFPA 1971, 1991 Edition.

"THIS STRUCTURAL FIRE FIGHTING PROTECTIVE GARMENT MEETS THE REQUIREMENT OF NFPA 1971, STANDARD ON PROTECTIVE CLOTHING FOR STRUCTURAL FIRE FIGHTING, 1991 EDITION. NFPA 1500, STANDARD ON FIRE DEPARTMENT OCCUPATIONAL SAFETY AND HEALTH PROGRAM, PROVIDES USE REQUIREMENTS FOR PROTECTIVE CLOTHING.

WARNING

FOR STRUCTURAL FIRE FIGHTING OPERATIONS, BOTH PROTECTIVE COAT AND PROTECTIVE TROUSERS MUST BE WORN FOR LIMB/TORSO PROTECTION. PROTECTIVE COAT/PROTECTIVE TROUSER OVERLAP IS REQUIRED BY NFPA 1500. OUTER SHELL, MOISTURE BARRIER, AND THERMAL BARRIER MEETING REQUIREMENTS OF NFPA 1971 MUST BE UTILIZED, AND ALL GARMENT CLOSURES MUST BE FASTENED WHEN IN USE. DO NOT USE PROTECTIVE COAT AND PROTECTIVE TROUSERS ALONE FOR STRUCTURAL FIRE FIGHTING OPERATIONS; OTHER PROTECTIVE EQUIPMENT - HELMET, SCBA, GLOVES, FOOTWEAR, PASS - IS REQUIRED FOR PROTECTION. DO NOT KEEP THIS GARMENT IN DIRECT CONTACT WITH FLAMES. THIS GARMENT ALONE MAY NOT PROVIDE PROTECTION FOR PROXIMITY OR FIRE ENTRY APPLICATIONS OR FOR PROTECTION FROM CHEMICAL, RADIOLOGICAL, OR BIOLOGICAL AGENTS. KEEP THE GARMENT CLEAN AS SOILING WILL REDUCE PROTECTIVE QUALITIES.

- DO NOT USE CHLORINE BLEACH -

CHLORINE BLEACH WILL SIGNIFICANTLY COMPROMISE THE PROTECTION AFFORDED BY THE TEXTILE AND FILM MATERIALS UTILIZED IN THE CONSTRUCTION OF THIS GARMENT. USERS MUST CLEAN, MAINTAIN, AND ALTER ONLY IN ACCORDANCE WITH MANUFACTURER'S INSTRUCTIONS. DO NOT STORE IN DIRECT SUNLIGHT. NO PROTECTIVE CLOTHING CAN PROVIDE COMPLETE PROTECTION FROM ALL CONDITIONS - USE EXTREME CARE FOR ALL EMERGENCY OPERATIONS. FAILURE TO COMPLY WITH THESE WARNINGS MAY RESULT IN SERIOUS INJURY OR DEATH."

Manufacturer's Name
Manufacturer's Address
Country of Manufacture
Manufacturer's Garment Identification Number
Date of Manufacture
Size
Cleaning and Drying Instructions
Garment Material(s)

"DO NOT REMOVE THIS LABEL"

USER INFORMATION GUIDE: Each individual garment shall include a User Information Guide with information required by NFPA 1971, latest revision. This guide will include cleaning instructions, maintenance criteria, methods of repair, warranty information, safety considerations, storage conditions, decontamination procedures, and retirement considerations.

WARRANTY: A limited lifetime warranty of materials and workmanship shall be given. This warranty, including a warranty registration postcard, shall be fully explained on card attached to each garment.

November, 1993

JANESVILLE

MASTER SPECIFICATIONS

COMMANDO

SUPER PANTS

SCOPE: This protective clothing is for conventional structural fire fighting only to protect the body, excluding head, hands, and feet against temperature extremes, steam, hot water, hot particles and other hazards encountered during fires and related emergencies. This protective clothing is not proximity or entry gear, and is not designed to be kept in direct contact with flames.

NFPA 1971: All construction, features, and fabrics in this specification must meet or exceed the requirements of NFPA Specification 1971, 1991 edition, OSHA 1910, Subpart L, and Cal-OSHA title 8, Article 10.1, Para 3406. Such features, fabrics, construction, trim, and other details, whether specifically enumerated in this specification or not, are the responsibility of the dealer, agent, manufacturer or other seller. Implied or direct conflicts between this specification and NFPA 1971, OSHA, Subpart L, and Cal-OSHA are not the intention of this specification, and will be eliminated by notifying the issuing authority and subsequent alteration of the specification.

OUTER SHELL MATERIAL: The Outer Shell shall be 100% Nomex® III of duck weave, and weigh approximately 7.5 oz. per square yard with a stain and water repellent finish. Color to be Black, Natural, Yellow, Lime-Yellow, Tan, Red.

OUTER SHELL MATERIAL: The Outer Shell shall be 60% Kevlar®, 40% PBI® rip stop weave, and weigh approximately 7.5 oz. per square yard with a stain and water repellent finish. Color to be Natural (PBI Gold), Black.

OUTER SHELL MATERIAL: The Outer Shell shall be 60% Kevlar®, 40% PBI®, rip stop weave, and weigh approximately 6.0 oz. per square yard with a stain and water repellent finish. Color to be Natural (PBI lightweight Gold)

OUTER SHELL MATERIAL: The Outer Shell shall be 60% Kevlar®, 40% Nomex®III rip stop weave, and weigh approximately 7.0 oz. per square yard with a stain and water repellent finish. Color to be Black, Tan, Rust, or Yellow.

THERMAL LINER MATERIAL: Thermal Liner shall be quilting composed of 100% dyed Nomex® pajama check face cloth quilted to 100% reprocessed (recycled) aramid batting, and weighing approximately 8.5 oz. per square yard. This material shall meet the requirements

of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be quilting composed of 100% dyed Nomex® pajama check face cloth quilted to three layers of spunlaced Nomex® SL/E89 aramid material of 85% Nomex® and 15% Kevlar®, and weighing approximately 7.5 oz. per square yard These materials shall meet the requirements of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be quilting composed of 100% dyed Nomex® pajama check face cloth quilted to 70% reprocessed Kevlar®/30% Virgin Kevlar® batting, and weighing approximately 7.05 oz. per square yard. This material shall meet the requirements of NFPA Standard 1971.

THERMAL LINER MATERIAL: Thermal Liner shall be "ARAFLO" composed of 100% Nomex® III face cloth quilted to three layers of apertured spunlaced SL/E89 aramid material with 11-13 apertures per sq. inch and weighing 7.5 oz. per square yard. These materials shall meet the requirements of NFPA Standard 1971.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 50%/50% Cotton/Polyester plain weave with an application of fire retardant neoprene. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 100% Nomex® with an application of fire retardant neoprene. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 100% Nomex® laminated to a lightweight film of breathable Teflon, "Gore-Tex" type, membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be spunlaced SL/E89 aramid material of 85% Nomex® and 15% Kevlar® laminated to a lightweight film of breathable Teflon, "Gore-Tex" type, membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition for waterproofness.

MOISTURE BARRIER MATERIAL: Moisture Barrier shall be 85% Nomex® and 15% Kevlar® laminated to a lightweight film of breathable Teflon, "Tetratex®, membrane. This material shall meet the requirements of NFPA Standard 1971, 1991 Edition, for waterproofness.

DESIGN: The pant shall be no more than one (1) inch higher in the front than a standard bunker pants with a gradual increase to four (4) inches in the rear.

THREAD: All thread to be Nomex, and of a minimum of 7-8 stitches per inch.

STITCHING: All stitching conforms to Federal Standard 751 Specifications (FED-STD-751).

RIVETING: All Outer Shell stress points, including top and bottom pocket corners, pocket flap corners, top and bottom of storm flap, harness snaps and Dee rings shall be riveted using two (2) piece, plated steel rivets, backed with split cowhide leather washers not less than 1" in diameter for additional strength.

PANT METAL CONTACT PREVENTION: The pant is to be constructed such that when completely assembled there shall be no direct metal contact from the exterior of the Outer Shell through the Thermal Liner to the wearer's body, unless the hardware is located on the waistband or hardware is completely covered by external closure flaps. This is intended to prevent a pathway for the conduction of heat to the skin, and shall apply to the use of all rivets, snaps, hooks, dees, zippers or any other metal used to fabricate the pant.

LUMBAR SUPPORT SYSTEM: Each pant shall have an integrated lumbar support system built into the Outer Shell. This device shall provide mechanical support for the back by generating intra-abdominal pressure without increasing abdominal muscle activity.

Components of the lumbar support system include a 6" x 9" long orthopedic foam pad encased in neoprene coated polyester/cotton, elastic webbing, metal adjusters, and pull tabs.

Lumbar support system shall be installed between the Outer Shell and Moisture Barrier and utilize a 6" wide x 9" long tunnel system made of neoprene coated polyester/cotton to guide the elastic webbing. Each pant front shall have two tunnel openings spaced 7" apart on the front of the pant. Pull tabs, made of 7.5 oz. sq./yd. Black Nomex®III, 1.5" wide x 5.5" long shall be sewn to 2" wide x 7.5" long pull straps and the pull straps are sewn to the elastic webbing. Elastic webbing shall be secured to center rear of pant. When lumbar support system is deactivated, pull tabs will be visible on front of pants. 2" wide x 3.5" long VELCRO pile shall be sewn on top of each pull strap, and 2" wide x 3.5" long VELCRO hook shall be sewn on underside of each pull strap to engage system. Left side of pant shall have 1.5" wide x 4" long VELCRO pile for storage of pull tab and to help engage system. Right side of pant shall have 2" wide x 4" long VELCRO pile for storage of pull tab and to help engage system. Foam pad shall have two 2" wide x 6" long strips of VELCRO pile to engage two 2" wide x 6" long strips of VELCRO hook sewn to rear of pant to hold foam pad in place.

OUTSIDE STORM FLY: The Outer Shell shall have an overlapping fly front running the full length of the fly on the left side. The flap shall not be less than 4" wide at the waistband, cut diagonally to the bottom of the fly where it shall be double reinforced with two plated steel rivets backed with split cowhide leather.

For additional protection against steam penetration, a polyester/cotton moisture barrier material shall be placed between the two pieces of Outer Shell material that make up the overlapping fly and shall run the full width and length of the fly.

THERMAL FLY ASSEMBLY: The Moisture Barrier-Thermal Liner system shall be constructed with an effective 3" extension on the left side at the waist of all layers of the fly opening to assure continuous thermal and moisture protection. This overlap is sandwiched between the Outer Shell layers of the outside storm fly. There shall be 1" wide by 9" long VELCRO hook sewn to the Moisture Barrier/Thermal Liner to engage corresponding VELCRO pile on the underside of the outside storm fly.

At the bottom of the fly opening this overlap shall be further secured by means of a bartack to prevent gaping at the base of the moisture barrier-thermal liner fly when the wearer is squatting or crawling. This bartack shall also serve to reinforce the front end of the seat seam if stretched or stressed.

OUTSIDE STORM FLY FRONT CLOSURE SYSTEM: Hook and dee ring closing for quick one motion closing at waist. The Hook shall be 2 1/2" in length, made of a zinc non-ferrous metal alloy and weigh 1.2 oz. + 5%. It will be securely fastened to the pant by means of a 5/8" wide, treated leather take-up strap looped through the rear of the buckle and double riveted to the pant shell with leather backed rivets. The Dee will be made of a non-ferrous metal alloy 2" long by 1 1/16" wide conforming to the general design shown in section 3-1.8 of NFPA 1971, latest revision.

(fly closure)
a) The storm fly shall be held closed along its length by means of a VELCRO closure one and one half (1 1/2) inch minimum width along the leading edge for a distance of not less than six (6) inches from the bottom of the fly closure to the waist area for proper alignment and secure closure. There shall be one (1) snap composed of a plated steel cap, socket, post, and stud positioned at the inside top of the fly.

b) The storm fly shall be held closed along its length by a heavy duty brass zipper. One half of the zipper shall be sewn inside of leading edge of storm fly. Other half shall be sewn along right front body panel and shall be positioned to engage zipper half of storm fly. The top of each zipper shall be reinforced with a bartack. Storm fly shall also be held closed by means of a VELCRO closure one and one half (1 1/2) inch minimum width.

MOISTURE BARRIER/THERMAL LINER CONSTRUCTION: The Moisture Barrier/Thermal Liner shall be designed to be compatible with the Outer Shell so it does not buckle, pull, or otherwise restrict body motion.

a) (Neoprene) The Moisture Barrier shall be completely sewn to the Thermal Liner at its perimeter with the Neoprene side facing

outward from the Thermal Liner. All edges are to be sewn together and bound with non-wicking Moisture Barrier material. All moisture barrier seams are to be sealed as required by the NFPA 1971, 1991 Edition. The Moisture Barrier/Thermal Liner shall be no more than three (3) inches from the cuff.

b) (Breathable) The Moisture Barrier shall be completely sewn to the Thermal Liner at its perimeter with the Teflon side facing inward toward the Thermal Liner. All edges are to be bound with a non-wicking Moisture Barrier material. All seams and stitch lines are sealed with Gore-Tex® Seam Tape to prevent leakage. The Moisture Barrier/Thermal Liner shall be no more than three (3) inches from the cuff.

MOISTURE BARRIER/THERMAL LINER ATTACHMENT:

a) COMPLETELY REMOVABLE: The Moisture Barrier/Thermal Liner shall be completely detachable from the Outer Shell for ease of cleaning by using not less than eleven (11) snaps - each composed of a plated steel cap, socket, post, and stud. There shall be no less than seven (7) snaps around the waist and two (2) snaps on each leg end. There shall be two (2) - 1 1/2" x 4" VELCRO strips placed at the waist in addition to the snaps.

b) COMPLETELY REMOVABLE WITH SUSPENDER LINER OUT: Liner out system for the pant shall consist of mounting eight suspender buttons appropriately space around the waist of the Moisture Barrier/Thermal Liner. The Outer Shell shall have eight (8) corresponding keyhole buttonholes to accommodate the suspender buttons on the Moisture Barrier/Thermal Liner. Each pair of keyhole buttonholes shall have an additional reinforcement of 2" x 5" neoprene coated polyester/cotton material sewn into the Outer Shell to support the buttonholes. This system will prevent the fire fighter from using the bunker pants without the aid of suspenders, as suspenders cannot be used without having both the Outer Shell and Moisture Barrier/Thermal Liner.

c) PERMANENTLY ATTACHED: The Moisture Barrier/Thermal Liner shall be sewn to the Outer Shell at the waist area. To further secure Moisture Barrier/Thermal Liner to waist area eleven (11) snaps - each composed of a plated steel cap, socket, post, and stud, shall be used. There shall be no less than seven (7) snaps around the waist and two (2) snaps on each leg end.

WAIST: The waist shall be turned under 1/2" to provide double material strength for liner attachment snaps and suspender button. Eight suspender buttons shall be appropriately spaced around the waistband to accommodate the use of suspenders.

EXTERNAL ADJUSTMENT DEVICE: One (1) adjustment device shall be affixed to the outside of the pant on each side.

Each take-up strap shall comprise of two sub-component straps. The front strap shall be (1) inch wide and (5) inches in length, folded

in half to form a loop, and shall be affixed on the side of pants by means of two bartacks spaced (2) inches apart. The loop shall face toward the back and hold a nickel plated 1" tourniquet buckle.

The back strap shall be (1) inch wide and (6) inches in length of double thickness outer shell material. The strap shall be affixed to the rear of the back of front body panels by means of two separate bartacks and positioned to allow the loose end to thread through the metal tourniquet buckle. The metal buckle shall allow for adjustment and shall firmly hold the take-up strap in the desired position. Hook and pile (e.g. Velcro) shall be used to secure the loose end of each take-up strap to respective component. A (1) inch by (4) inch piece of pile fastener tape shall be installed horizontally on each back take-up strap. A (1) inch by (2) inch piece of hook fastener tape shall be installed at the end of the take-up strap and shall be positioned to engage the loop fastener tape.

THERMAL ENHANCED SEAT: There shall be an additional layer of thermal material added to the inner layer between the moisture barrier and thermal liner. The material shall be spunlaced SL/E89 aramid material, of 85% Nomex® and 15% Kevlar® shall be sewn to the inside of the thermal liner. The additional layer shall start 5" down from the top center of the rear of the pant. The seat reinforcement shall extend 11" down and measure 16" across. The thermal enhanced seat will add enhance thermal protection in areas exposed when crawling or bending.

RADIAL INSEAM BAND: The pant shall incorporate a comfort/mobility design. This design will remove crotch seams, which will decrease the bunching of material allowing for a more comfortable fit. Mobility will be gained through this design by increasing leg circumference to allow for less restriction of leg movement.

The banded pant insert will run continuously from the top of the mobile knee of one leg, through the crotch, to the top of the mobile knee of opposite leg. The band will be dimensionally configured from a center point of 6" to a graduated taper of 5" at the top of the mobile knee, and shall be double needle felled stitched. The design shall be in all layers.

KNEE DESIGN: The knee area shall incorporate a comfort/mobility design. This design will allow for a natural bending motion of the knee. The knee shall be (pearl gray split cowhide leather, black split cowhide leather, self-material, Arashield) and measure 11" across the bottom, not less than 7" on the sides and gradually increase to 10" at the center point at the apex. The apex of the knee will allow for not less than a 1½" bellows at the center. The radial seam provides a gusset that the knee can fall into when crawling, climbing, bending, etc.... The bottom of the mobile knee should be placed not less 10" from the cuff to fall anatomically correct. For added thermal protection an additional layer of spunlaced SL/E89 aramid material, of 85% Nomex® and 15% Kevlar® shall be sewn to the inside of the thermal liner. The material

shall weigh 2.7 oz. per square yard. The mobile knee design shall be incorporated into all layers of pants.

PADDED KNEES: In addition to reinforcement, knees shall be padded using one layer of neoprene coated nonwoven aramid material. The reinforcement material shall be sandwiched between the Outer Shell and knee reinforcement. Neoprene shall face outward.

PANT CUFFS: The cuff area of the pant shall be reinforced with a binding of (pearl gray split cowhide leather, black split cowhide leather, outer shell fabric), not less than 2" in total width for greater strength, abrasion resistance, and thermal protection.

OUTER SHELL REFLECTIVE CUFF PATTERN: Scotchlite, Dual-Trim Scotchlite, Reflexite. Trim/Color Red-Orange, Lime-Yellow, shall be applied as follows: One (2,3)" strip completely around bottom of the cuff 2-3 inches from the bottom hem. All trim to be sewn with Stitch 301, minimum 6 stitches per inch.

OUTER SHELL BELLOWS POCKETS, FLAPS, AND CLOSURE: The pant is to have two (2) outside full bellows pocket(s) sized 8" wide, 8" deep that expand by means of side and bottom gussets to a thickness of 2" in front and back. The right side pocket should be split 4" front and 4" back.

a) The pockets shall be fully lined with Kevlar Twill. The back of the pocket (pant leg) shall be similarly reinforced to height of 3". The twill material shall no unfinished seams showing.

b) Pockets to be reinforced with (pearl gray split cowhide leather, black split cowhide leather, self material) which extends down the bottom 5" of the outside of the pocket. Inside the pocket pearl gray split cowhide leather shall reinforce the pant front which forms the back side of the pocket to a height of 3" above the bottom of the pocket.

The pocket(s) shall be set with Stitch 301, Seam Ssb-2 with the top and bottom pocket corners reinforced with plated steel rivets backed with split cowhide leather for additional strength. Drainage of moisture to be provided by eyelets. Pockets shall be located one on each fore thigh.

Pocket flaps shall be 9" x 4½" folded and stitched at 1½" width to correspond with pocket gussets. The flap shall then extend 3" down to give a creased and contoured pocket flap. The flaps shall be formed using Stitch 301, Seam Ssa-1, turned, and topstitched using Stitch 301, Seam Ssc-2. They shall be set using Stitch 301, Seam Ssn-2, inverted and reinforced at each top corner with one (1) plated steel, split cowhide leather reinforced rivet.

Hook and Pile VELCRO closure system mounted such that a 1½" x 8" pile is on the pocket and two (2) pieces 1½" x 2¾" cam stitched hook is on the underside of the flap spaced no less than 4" apart.

PANT SIZING: Pant shall be available in even waist sizes. Pant shall be available in Extra Short, Short, Regular, and Long inseam lengths.

LABELING-REQUIREMENTS: The garment shall be labeled in accordance of the requirements of NFPA 1971, 1991 revision.

"THIS STRUCTURAL FIRE FIGHTING PROTECTIVE GARMENT MEETS THE REQUIREMENT OF NFPA 1971, STANDARD ON PROTECTIVE CLOTHING FOR STRUCTURAL FIRE FIGHTING, 1991 EDITION. NFPA 1500, STANDARD ON FIRE DEPARTMENT OCCUPATIONAL SAFETY AND HEALTH PROGRAM, PROVIDES USE REQUIREMENTS FOR PROTECTIVE CLOTHING.

WARNING

FOR STRUCTURAL FIRE FIGHTING OPERATIONS, BOTH PROTECTIVE COAT AND PROTECTIVE TROUSERS MUST BE WORN FOR LIMB/TORSO PROTECTION. PROTECTIVE COAT/PROTECTIVE TROUSER OVERLAP IS REQUIRED BY NFPA 1500. OUTER SHELL , MOISTURE BARRIER, AND THERMAL BARRIER MEETING REQUIREMENTS OF NFPA 1971 MUST BE UTILIZED, AND ALL GARMENT CLOSURES MUST BE FASTENED WHEN IN USE. DO NOT USE PROTECTIVE COAT AND PROTECTIVE TROUSERS ALONE FOR STRUCTURAL FIRE FIGHTING OPERATIONS; OTHER PROTECTIVE EQUIPMENT - HELMET, SCBA, GLOVES, FOOTWEAR, PASS - IS REQUIRED FOR PROTECTION. DO NOT KEEP THIS GARMENT IN DIRECT CONTACT WITH FLAMES. THIS GARMENT ALONE MAY NOT PROVIDE PROTECTION FOR PROXIMITY OR FIRE ENTRY APPLICATIONS OR FOR PROTECTION FROM CHEMICAL, RADIOLOGICAL, OR BIOLOGICAL AGENTS. KEEP THE GARMENT CLEAN AS SOILING WILL REDUCE PROTECTIVE QUALITIES.

- DO NOT USE CHLORINE BLEACH -

CHLORINE BLEACH WILL SIGNIFICANTLY COMPROMISE THE PROTECTION AFFORDED BY THE TEXTILE AND FILM MATERIALS UTILIZED IN THE CONSTRUCTION OF THIS GARMENT. USERS MUST CLEAN, MAINTAIN, AND ALTER ONLY IN ACCORDANCE WITH MANUFACTURER'S INSTRUCTIONS. DO NOT STORE IN DIRECT SUNLIGHT. NO PROTECTIVE CLOTHING CAN PROVIDE COMPLETE PROTECTION FROM ALL CONDITIONS - USE EXTREME CARE FOR ALL EMERGENCY OPERATIONS. FAILURE TO COMPLY WITH THESE WARNINGS MAY RESULT IN SERIOUS INJURY OR DEATH."

Manufacturer's Name
Manufacturer's Address
Country of Manufacture
Manufacturer's Garment Identification Number
Date of Manufacture
Size
Cleaning and Drying Instructions
Garment Material(s)

"DO NOT REMOVE THIS LABEL"

USER INFORMATION GUIDE: Each individual garment shall include a User Information Guide with information required be NFPA 1971, 1991 revision. This guide will include cleaning instructions, maintenance criteria, methods of repair, warranty information, safety considerations, storage conditions, decontamination

procedures, and retirement considerations.

WARRANTY: A limited lifetime warranty of materials and workmanship shall be given. This warranty, including a warranty registration postcard, shall be fully explained on a card attached to each garment.

ENCLOSURE 2

Recommendations for Sensory Simulation

from the

Institute for Simulation and Training

Simulation of Fire in a Virtual Environment

Sensory Simulation

Submitted to
Global Technology Associates, Inc.

by

Institute for Simulation and Training
University of Central Florida
3280 Progress Drive
Orlando, Florida

May 30, 1996

Kimberly Abel Parsons

Simulation of Fire in a Virtual Environment

Sensory Simulation

Prepared for

Global Technology Associates, Inc.
Orlando, Florida

Submitted by the

Institute for Simulation and Training
University of Central Florida
Orlando, Florida

Prepared by

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Institute for Simulation and Training
University of Central Florida

May 30, 1996

This final report is submitted to Global Technology Associates (GTA), Inc., Orlando, Florida, as a deliverable for contract N94249.

The report provided contains the following:

Sensory Simulation
- Introduction
- Head Mounted Displays
- Spacial Sound
- Heat Sensors and Actuator Transducers Requirements for Virtual Environment Users - Physiological Considerations

Sensory Simulation

INTRODUCTION

The following material will discuss some theoretical aspects of HMDs and the importance of visual input for a true immersion in the virtual space. Also, the importance and some theoretical considerations about the sound input in virtual environments is presented in the second part.

We have considered that knowing better the mechanisms of "immersion" in the virtual environment will allow a better analysis of the available systems on the market, and, at the same time, a better understanding of the real requirements for a specific virtual reality system.

For HMDs we found some we have found some measures which can show us a true representation of the quality and performance/price ratio of different commercial systems.

For HMDs and sound systems we have studied different factors involved in the accuracy of a simulation and at the same time we compared different systems in terms of price and features offered.

Furthermore we have studied some physiological aspects of the heat sensors and heat actuator transducers which will allow us to have a better understanding of the heat simulation and heat measurements.

Head Mounted Displays

Head Mounted Displays

Calin Cojocariu

Institute for Simulation and Trianing
University of Central Florida

Definitions:

Head Mounted Displays (HMD)

A set of goggles or a helmet with tiny monitors in front of each eye that generate images, seen by the wearer as being 3-D

Shutter Glasses

LCD screens or physically rotating shutters used to see stereoscopically when linked to the frame rate of a monitor

Head Coupled

Displays or robotics actions that are activated by head motion through a head tracking device

(From Virtual Reality Terms by Joe Psotka and Sharon Davison, http://198.97.199.60/vrterms.html)

Introduction

HMDs are worn more or less like eyeglasses. Images on the display usually block the images of the real world, but some displays have a see through mode in which images are superimposed on the real world.

A head tracker is used with every computer driven HMD so that the image generator can keep up with the user's position and direction of view. In this way the user becomes immersed in a virtual world of computer graphics imagery and can explore that world from all viewpoints. In general, HMDs are used to provide information to people where ordinary direct view display are either inappropriate or impractical. HMDs have unique applications in virtual environments where total immersion is important, in environments where hands-free operation is desirable or necessary, and in applications involving unique viewing requirements. [1]

Buying a HMD can be a real problem. Due to the variety of configurations that are available on the market, it is very difficult or, sometimes, practically impossible to evaluate and compare different models one with an other. The technical sheets are often confusing due to the large amount of numerical data that, some times, seems

contradictory. We will try to evaluate four important factors involved in overall quality and price/performance ratio:

- **Image quality**: The best way to evaluate the perceived image quality from the user point of view is to use the angular resolution approach [2].
- **Field of view**(FOV): Horizontal FOV is the most important in achieving the impression of "immersion"
- **Weight:** Display weight and balance are important for the user comfort.
- **Price.**

ANGULAR RESOLUTION

⇒ See HMD table and Angular resolution chart

This measure offers the big advantage to make it possible to compare HMDs that are strictly different from a hardware point of view (i.e.: LCD vs CRT based HMDs, different resolutions of images generators, etc.).

The evaluation of resolution takes into account two important factors:

- The resolution of the internal display system (LCD or CRT) .
- The horizontally covered field of view (FOV)

Therefore, since the evaluation in terms of minutes of arc per pixel includes these two factors, it becomes independent of these characteristics that are common to all HMDs. We can now compare these HMDs with a normalized measure which will give us a better idea of the overall visual quality perceived (see "Arc minutes/pixel" table).

Let us first define what an arc minute per pixel is. One arc minute represent 1/60 of a degree. Hence, the angle defined by the left and right extent of a picture element (pixel) define a value in arc minute per pixel. The figure 1a illustrate this definition.

For the human, the maximum angular resolution of the eye is around 1 arc minute for the smallest point that can be seen. This visual acuity is localized at the fovea region on the retina where there is the higher density of cones. These cones are mostly responsible of the color vision.

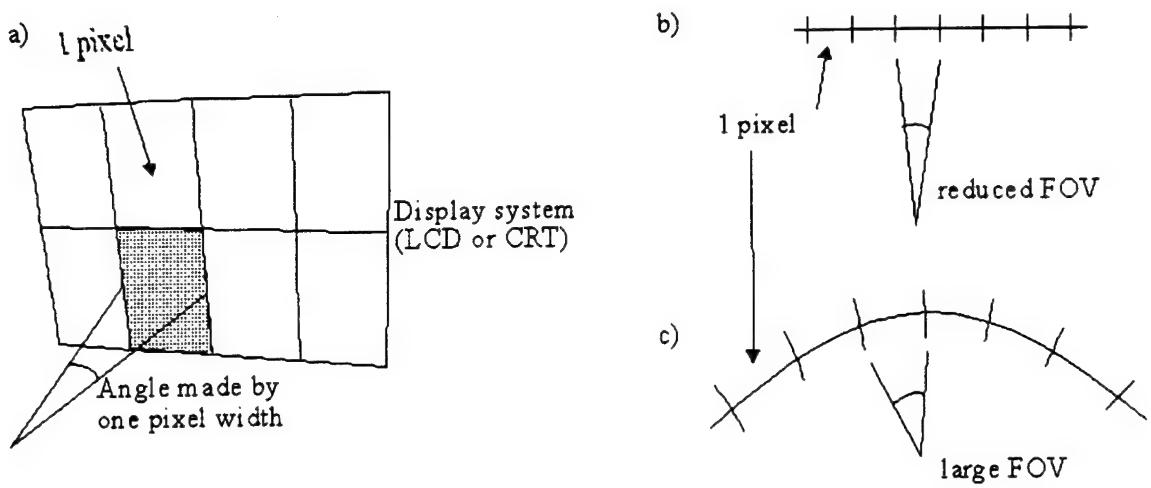


Figure 1

Always keep in mind that the smaller values represent the best visual quality. Ideally, the angular resolution for a given HMD helmet should be lower than 4.76 minutes of arc per pixel. This value is equivalent to the image quality perceived at 2 feet's of a 14" computer monitor which is in 320 x 200 graphic mode.

FIELD OF VIEW

⇒ See HMD table and FOV graphs

The second parameter we must consider is the field of view (FOV). The values for each HMD model are given in the HMD table. An important note about these values: It's quite difficult to build up such a table of FOV values for different HMDs. This is due to the fact that there is no actual standard in the way manufacturer gives these numbers. Also, note that at least 20 degrees overlap is needed to suite the human visual system.

FOV specifies how much of the scene can be observed at one time. One hears of minimum FOV necessary to achieve "immersion", meaning the minimum necessary to give the impression of being in the virtual world rather than being an observer of it. Horizontal FOV of 80 to 100 degrees are often cited as the threshold for immersion [1]. Wider FOVs are certainly more impressive but is not so clear if above the threshold necessary for achieving immersion a wider FOV will result in improved perception. Also, wider FOVs inevitably come at the expense of reduced resolution and the trade-off will depend upon individual preference and the task to be accomplished with the display.

A few systems provide a high resolution inset. The principle is to match the characteristics of the human eye in which the visual acuity is much higher near the center of the direction of view. Ideally, the high resolution region should be moved to match the motion of the eye.

WEIGHT

⇒ See HMD table and Weight graph.

Display weight and balance are important for user comfort. Anything over 4lbs. will pose a fatigue problem if worn for more than a few minutes, as will a display with a pound or two out of balance.

Usually the LCD displays will weight less compared with the CRT displays but, at the same time, the LCD displays will have less resolution. There are HMDs with a CRT based display with acceptable low weight and also LCD based HMDs with very low weight and high resolution. The decision for acquisition of such a display should take into consideration all these factors (see the comparison charts for LCD and CRT displays)

PRICE

⇒ See HMD table and Price graph

Products tend to fall into two categories: LCD-based products costing US $10,000 and below, and CRT or fiberoptic products costing US $50,000 or more. The high end products sometimes require external devices to convert from composite color to field sequential color, which can add another $20,000 to the cost of implementation. The large gap in price and performance between the two categories has not gone entirely unnoticed.

Generally you get what you pay for. The market is too competitive for any vendor to get far out of line in providing performance for price. The expensive products produce the best imagery, but they do tend to have the drawback of being heavier and more cumbersome than the low-cost LCD products.

Other Features

Eye spacing ought to be adjustable for each individual wearing the display. For transient users like those experiencing a four-minute VR game, the eye spacing adjustment may not be so critically important. Long-session users, however, should worry about the chronic eye-strain of having improper spacing.

Because the retinal images generated in a stereoscopic head-mounted display (HMD) are not projections from the real world, they may incorporate artifacts that can impair normal visual function. The more commonly occurring artifacts include:

- Differences in image size in the two eyes
- Differences in image resolution in the two eyes

- Differences in image contrast in the two eyes
- Display centers wider or narrower than interpupillary distance
- Displays rotated with respect to each other
- Displays at different elevations with respect to the two eyes
- Open-loop disparity/vergence/accommodation relationship
- Conflicting depth cues

Some of these artifacts will produce immediate visual effects, such as the inability to fuse the stereoscopic images, while others will require excessive or sustained effort of the extraocular muscles to maintain fusion, which can cause ocular discomfort, if left uncorrected.

Head mounted displays have many design peculiarities, and we recommend trying a particular display before purchasing one. Some units will not accommodate a user with a large head. Other units will not work with a user who has both a large head and a large nose. The combination of large head and small nose may result in the eye position being too close to the optics, with resulting severe eyestrain. Some units will not accommodate eyeglasses, and may or may not have enough range of focus to encompass the user's eyeglass prescription.

References:

[1] "Head Mounted Display Survey: A Comprehensive Round-up of Products" in Real Time Graphics, vol.4, no.2, Aug. 1995.

[2] "Resolution analysis for HMD helmets" by Marc Bernatchez, Http://www.gel.ulaval.ca/~mbernat/analyhmd/analysis.html

[3] " sci.virtual-worlds Head Mounted Displays (HMD) Frequently Asked Questions (FAQ)" by Toni Emerson, HITLab, University of Washington, Human Interface Technology Laboratory, PO Box 352412, Seattle, WA, 98195-2412, Ftp://ftp.hitl.washington.edu/pub/scivw/hmd-faq

HMD Vendor List

3D-MAX
Tel: +46 (0)18 18 77 77/Fax: +46 (0)18 51 66 00
Email: sales@ThreeD-MAX.udac.se
WWW: http://www.threed-max.udac.se/, http://pcvr.kasan.co.kr
product: 3D-Max

Astounding Technologies Inc.
950 Benecia Avenue
Sunnyvale, CA 94086 USA
Tel: 1-408-522-0300/Fax: 1-408-522-0310
product: Video Visor

CAE Electronics Ltd
8585 Cote de Liesse
C.P. 1800 Saint-Laurent
Quebec, Canada H4L4X4
Tel: 1-514-341-6780/Fax: 1-514-341-7669
product: Fiber-Optic HMD, Telepresence Visual System

Division LTD
Bristol, England
Tel: +44-0545-615554/Fax: +44-0454-615532
Division Inc: Tel: 1-800-877-8759
WWW: http://www.division.co.uk
product: dVISOR

Division, Inc.
The Courtyard, #10
431 West Franklin St.
Chapel Hill, NC 27516 USA
Tel: 1-919-968-7795/Fax: 1-919-968-7890
Email: info@division.com
product: dVISOR

Division, Inc. - Redwood City, CA USA
Tel: 1-415-364-6067/Fax: 1-415-364-4663
product: dVISOR

Fakespace, Inc.
4085 Campbell Ave.
Menlo Park, CA 94025 USA
Tel: 1-415-688-1940/Fax: 1-415-688-1949
Email: fakespce@well.sf.ca.us
product: BOOM3C, BOOM3M, BOOMD3C, BOOMD3M, PIVOT, FS2, MedView

FORTE Technologies Inc.
Paul Matthews
1057 E. Henrietta Rd.
Rochester, NY 14623 USA
Tel: 1-716-427-8595/Fax: 1-716- 292-6353
Email: support@fortech.com
WWW: http://www.fortevr.com
product: VFX1

General Reality Company
124 Race Str.
San Jose, CA 95126 USA
Tel: 1-408-289-8340/Fax: 1-408-289-8258
Email: sales@genreality.com
product: ACE-100M, ACE100S

Hughes Training Inc.
Link Division
PO Box 1237
Binghamton, NY 13902-1237 USA
Tel: 1-607-721-4356/Fax: 1-607-721-5600
product: ClearVue

Kaiser Electro-Optics
2752 Loker Ave. West
Carlsbad, CA 92008 USA
Tel: 1-619-438-9255/Fax: 1-619-438-6875
Email: kaisereo@cerfnet.com
product: VIM 1000pv, VIM3/EYE, SIM EYE 60, SIM EYE 60, Full Immersion HMD-1

Kopin Corporation
Innovision Center
160-A Albright Way
Los Gatos, CA 95030 USA
Tel: 1-408-264-0271/Fax: 1-408-274-0272
product: Mobile Assistant Head-Set

LEEP Systems Inc.
241 Crescent Street
Waltham, MA 02154-3425 USA
Tel: 617-647-1395/Fax: 617-899-9602
product: Cyberface 4, Cyberface 5

Liquid Image Corporation
659 Century Street
Winnipeg, Manitoba
R3H 0L9 Canada
Shannon O'Brien, Director Marketing and Sales
Tel: 1-204-775-2633/Fax: 1-204-772-0239
WWW: http://www.mbnet.mb.ca/~havelk/
product: MRG2.2, MRG3C, MRG4, MRG5

Nissho Electronics Corp.
Advanced Electronics Systems Division
70301 Tsukiji, Chuo-ku
Tokyo 104 JAPAN
Tel: 81-3-3544-8452/Fax: 81-3-3544-8284
product: STV-01, Eyephone NewHRX

nVision Inc.
7915 Jones Branch Drive
Suite 1B10
McLean, VA 22102 USA
Tel: 1-703-506-8808/Fax:1-703-903-0455
product: Datavisor 9ci and 10x

O.I.P. NV/SA

Westerring 21
B-9700 Oudenaarde, Belgium
Tel: +33-55-333-811/Fax: +33-55-316-895
product: HOPROS

RPI-ATG
PO Box 14607
San Francisco, CA 94114 USA
Tel: 1-415-495-5671/Fax: 1-415-495-5124
Email: fastar99@aol.com
product: HMSi Micro Model 900, HMS-EYE2, HMD model 975B, CHECK MATE 100, HIGH VIEW 180

SEOS Displays, Ltd.
Marchants Way
Burgess Hill, West Sussex RH15 8QY
United Kingdom
Tel: +44-1444-870-888/Fax: +44-1444-870-777
product: HMD (research project)

Shimadzu Corporation
Shimadzu Precision Instruments
20410 Earl Street
Torrance, CA 90503 USA
Tel: 1-310-214-0314/Fax: 1-310-542-0995
Email: Iniimi@aol.com
product: STV-01

Stereographics
product: Crystal Eyes shutter glasses

VictorMaxx Technologies
501 Lake Cook Road, Suite 100
Deerfield, IL 60015
Tel: 1-708-267-0007/Fax: 1-708-267-8669
Email: cybrmaxx@aol.com
WWW: http://vv.carleton.ca/sponsors/victormaxx/
product: CyberMaxx 180K

Virtual i-O, Inc.
Suite 600
1000 Lenora Street
Seattle, WA 98121 USA
Tel: 206-382-7410/Fax: 206-382-8810
Email: info@vio.com
WWW: http://www.vio.com
product: i-glasses!

Virtual Reality Inc.
333 Meadowlands Parkway, Second Floor Secaucus NJ 07094 Tel: 201-392-9800/Fax: 201-392-0156
product: HMD 133

Virtual Reality Research Systems Inc.
2326 Walsh Ave.
Santa Clara, CA 95051 USA
Tel: 1-408-748-8712/Fax: 1-408-748-8714
Email: virtualres@aol.com
product: VR 4, VR 4000, VR 5, EyeGen 3

Virtuality Entertainment, Inc.
Suite 105
7801 Mesquite Bend Drive
Irving, TX 75063 USA
Tel: 1-214-556-1800/Fax: 1-214-556-1890
WWW: http://www.virtuality.com/
product: Visette

Visionics Corporation
Suite 600
1000 Boone Avenue North
Minneapolis, MN 55427 USA
Tel: 1-612-544-4950/Fax: 1-612-544-4784
product: Visionics Low Vision Enghancement System

Vista Controls Inc.
27825 Fremont Court
Santa Clarita, CA 91355 USA
Tel: 1-805-257-4430/Fax: 1-805-257-4782
product: See-Thru-Armor, Vista Vison

Head Mounted Displays

Company	Model	H FOV	V FOV	Overlap	H res.	V res.	Res	ARes	Display	Wt.	Price	Comments
Astounding Technologies	2001 Video Visor	30	22.5	100	428	244	104432	4.21	Active-matrix LCD	14	$795	
CAE Electronics	Fiber-Optic HMD	120	55	25	1000	1000	1000000	7.20	Dual CRT	72	N/A	Display: CRT projector through fiber optics
Division	dVISOR	105	41	40	345	259	89355	18.26	Active-matrix LCD	80	$5,000	
FakeSpace	BOOMD3C	140	90	100	1280	1024	1310720	6.56	Dual CRT	N/A	$45,000	
FakeSpace	FS2	140	90	100	1280	1024	1310720	6.56	Dual CRT	N/A	$95,000	Tracking: 6DOF optomechanical
FakeSpace	MedView	30	30	100	1280	960	1228800	1.41	Dual CRT	N/A	$95,000	Tracking: 6DOF optomechanical
FakeSpace	PIVOT	140	90	100	1280	1024	1310720	6.56	Dual CRT	N/A	$45,000	
Forte Technologies	VFX1	48	35.2	100	428	244	104432	6.73	Active-matrix LCD	20	$895	Tracking: proprietary 3DOF sourceless "Virtual Oreintation System"
General Reality	CyberEye ACE-200N	35	26	100	789	230	181470	2.66	Active-matrix LCD	16	$2,595	
General Reality	CyberEye CE-200N	22.5	16.8	100	789	230	181470	1.71	Active-matrix LCD	14	$1,895	
General Reality	CyberEye CE-200W	35	26	100	789	230	181470	2.66	Active-matrix LCD	14	$1,995	
Hughes Training	ClearVue	80	40	30	1280	1024	1310720	3.75	Dual CRT	53	$100,000	Monochrome CRT with LC filters
Kaiser Electro-Optics	Full Immersion HMD-1	150	50	40	1153	300	345900	7.81	Active-matrix LCD	32	$50,000	6 LCDs per eye
Kaiser Electro-Optics	SIM EYE 40	60	40	100	1280	1024	1310720	2.81	Dual CRT	72	$145,000	Tracking: optional
Kaiser Electro-Optics	SIM EYE 60	100	60	100	1280	1024	1310720	4.69	Dual CRT	83	$165,000	Tracking: optional
Kaiser Electro-Optics	VIM 1000pv	100	30	100	800	225	180000	7.50	Active-matrix LCD	26	$6,495	Tracking: Polhemus optional
Kaiser Electro-Optics	VIM 3/EYE	116	30	100	1380	640	883200	5.04	Active-matrix LCD	N/A	N/A	3 LCDs per eye;Under development
Kaiser Electro-Optics	VIM 500pv	40	30	100	237	225	53325	10.13	Active-matrix LCD	24	$2,495	Tracking: Polhemus optional
Kopin	Mobile Assistant Head-Set	26	19	100	640	480	307200	2.44	Active-matrix LCD	10	$1,500	Monocular LCD, Traking: none
LEEP Systems	CyberFace 2	140	110	100	319	117	37323	26.33	Active-matrix LCD	32	$8,100	Tracking: not included;Single large-format LCD, divergent axis
LEEP Systems	CyberFace 3	80	60	100	480	120	57600	10.00	Active-matrix LCD	28	$17,105	Tracking: mechanical, 3DOF
LEEP Systems	CyberFace 4	80	60	100	640	480	307200	7.50	Active-matrix LCD	30	$18,400	Tracking: mechanical, 3DOF
LEEP Systems	CyberFace 5	140	110	100	1170	202	236340	7.18	N/A	N/A	$45,000	Under development
Liquid Image	MRG 2.2	84	65	100	240	240	57600	21.00	Active-matrix LCD	64	$3,495	Display: single large format LCD;Tracking: accomodates all Ascension and Polhemus trackers
Liquid Image	MRG3c	84	65	100	256	556	142336	19.69	Active-matrix LCD	64	$5,500	Display: single large format LCD
Liquid Image	MRG4	61	46	100	160	234	37440	22.88	Active-matrix LCD	32	$2,195	Display: single large format LCD
Nissho Electronics	Eyephone NewHRX	110	77	43	920	480	441600	7.17	Active-matrix LCD	48	$80,000	
nVision	Datavisor 10x	51.5	37	100	1280	1024	1310720	2.41	Dual CRT	56	$44,900	Overlap: 0-100 adjustable
nVision	Datavisor 80	80	37	100	1280	1024	1310720	3.75	Dual CRT	78	$105,000	Overlap: 0-100 adjustable
nVision	Datavisor VGA	52	37	100	640	480	307200	4.88	Dual CRT	48	$24,900	Overlap: 0-100 adjustable
OIP	HOPROS	20	20	100	640	480	307200	1.88	Dual CRT	28	$7,000	Tracking: head and eye tracking technology under develpment
RPI ATG	CHECK MATE 100	120	40	100	2481	684	1697004	2.90	Active-matrix LCD	19	$41,050	
RPI ATG	HIGH VIEW 180	25	19	100	827	428	353956	1.81	Active-matrix LCD	4	$1,850	
RPI ATG	HMD Model 975B	55.2	36	85	316	230	72680	10.48	Active-matrix LCD	33	$9,975	
RPI ATG	HMS-EYE2	55.2	36	85	316	230	72680	10.48	Active-matrix LCD	16	$1,850	
RPI ATG	HMSI Micro Model 900	65	40	100	473	218	103114	8.25	Active-matrix LCD	4	$3,500	Prototye

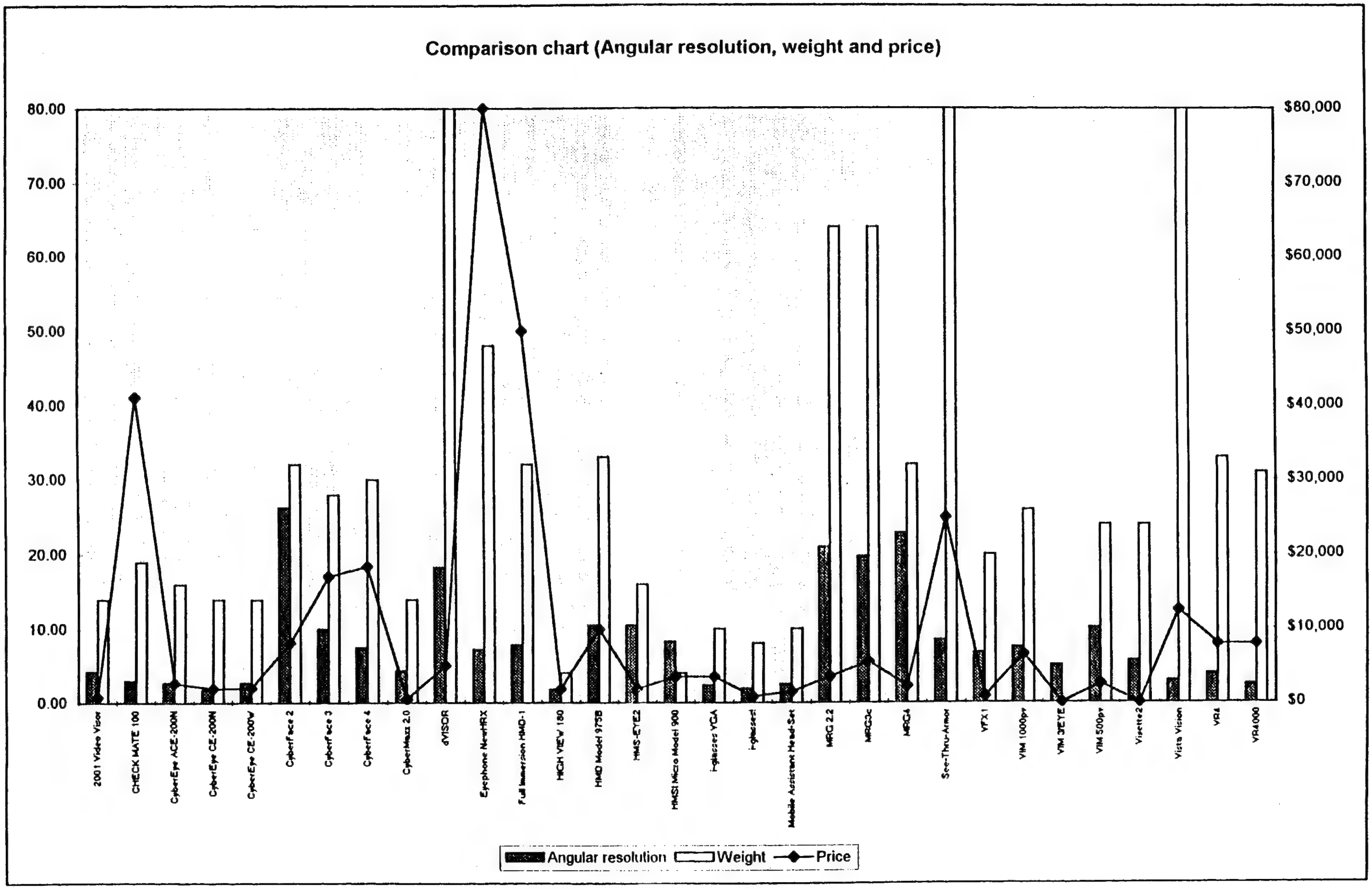
Head Mounted Displays

RPI ATG	Silicon Window 3C	60	65	100	1280	1024	1310720	2.81	Dual CRT	N/A	$59,000	
Shimadzu Corp.	STV-01	60	36	100	600	480	288000	6.00	Dual CRT	N/A	N/A	Display: monochrome CRTs with color wheels
VictorMaxx	CyberMaxx 2.0	56	42	100	780	230	179400	4.31	Active-matrix LCD	14	$499	Tracking: 3 DOF, 360 degrees yaw, +/-45 degrees pitch/yaw
Virtual I-O	i-glasses VGA	25	25	100	640	480	307200	2.34	Active-matrix LCD	10	$3,500	Monochrome display!
Virtual I-O	i-glasses!	25	19	100	789	230	181470	1.90	Active-matrix LCD	8	$799	Tracking: HEAD TRACKER 3 degrees of freedom: pitch, roll and yaw, 250 Hz sample rate
Virtual Reality	HMD133	40	30	100	1280	960	1228800	1.88	Dual CRT	48	$40,000	
Virtual Research	FS5	42.4	31.8	100	640	480	307200	3.98	Dual CRT	32	$19,900	Tracking: supports standard trackers
Virtual Research	VR4	48	36	100	742	230	170660	3.88	Active-matrix LCD	33	$7,900	Tracking: supports standard trackers
Virtual Research	VR4000	30	22.5	100	732	230	168360	2.46	Active-matrix LCD	31	$7,900	Tracking: supports standard trackers
Virtual Research	VR5	45	33	100	800	800	640000	3.38	Dual CRT	38	$19,900	Tracking: supports standard trackers
Virtuality	Visette2	60	46.8	100	640	480	307200	5.63	Active-matrix LCD	24	N/A	Price: designed to interface to Virtuality's entertainment system, not priced separately
Vista Controls	See-Thru-Armor	40	30	100	284	213	60492	8.45	Active-matrix LCD	80	$25,000	
Vista Controls	Vista Vision	32	24	100	640	480	307200	3.00	Active-matrix LCD	80	$12,500	

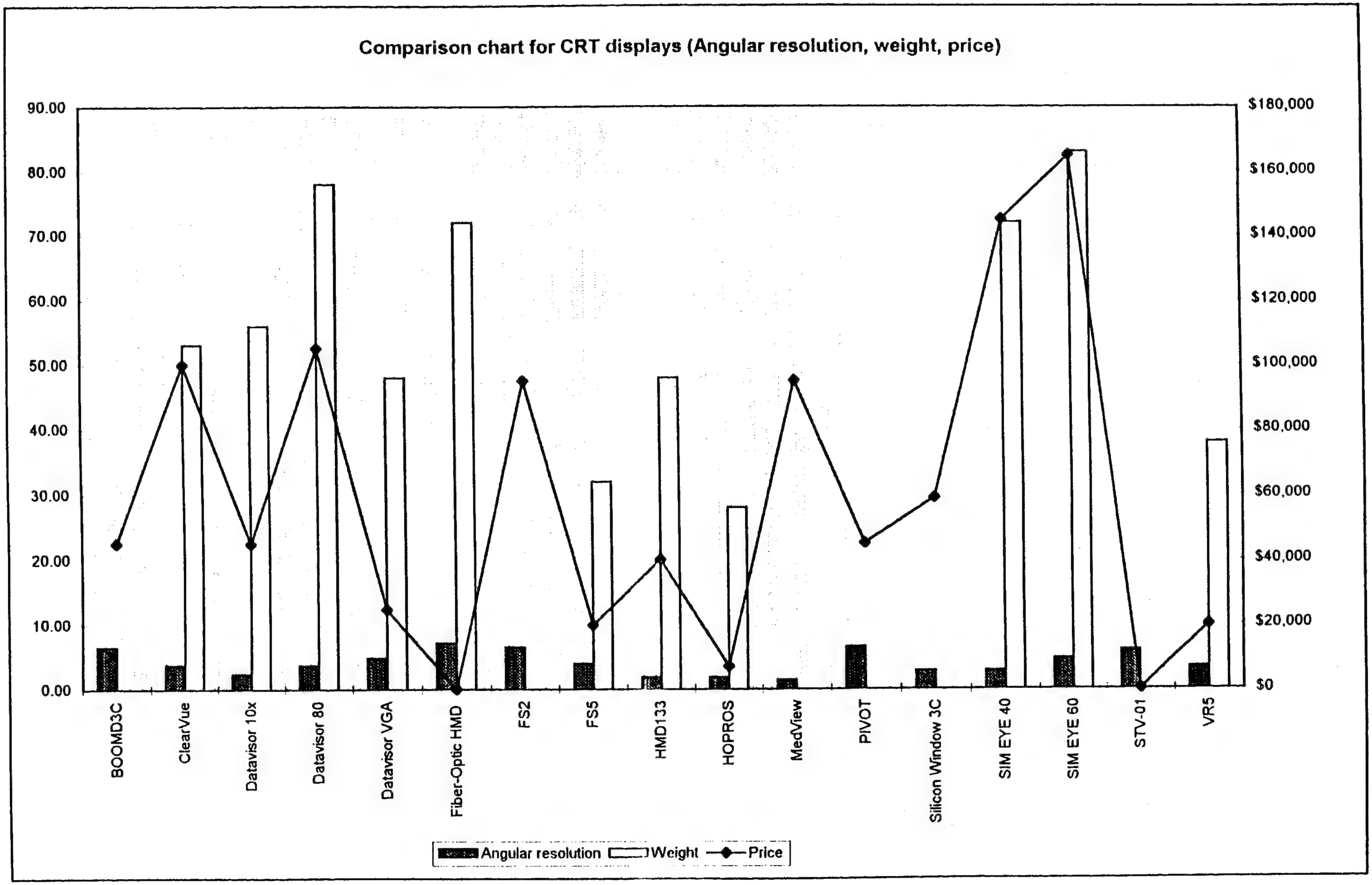
Legend:

H FOV = Horizontal field of view
V FOV = Vertical field of view
H Res = Horizontal resolution in pixels
V Res = Vertical resolution in pixels
Res = Total number of pixels
Ares = Angular resolution in arc minutes/pixel
Wt = Weight in ounces

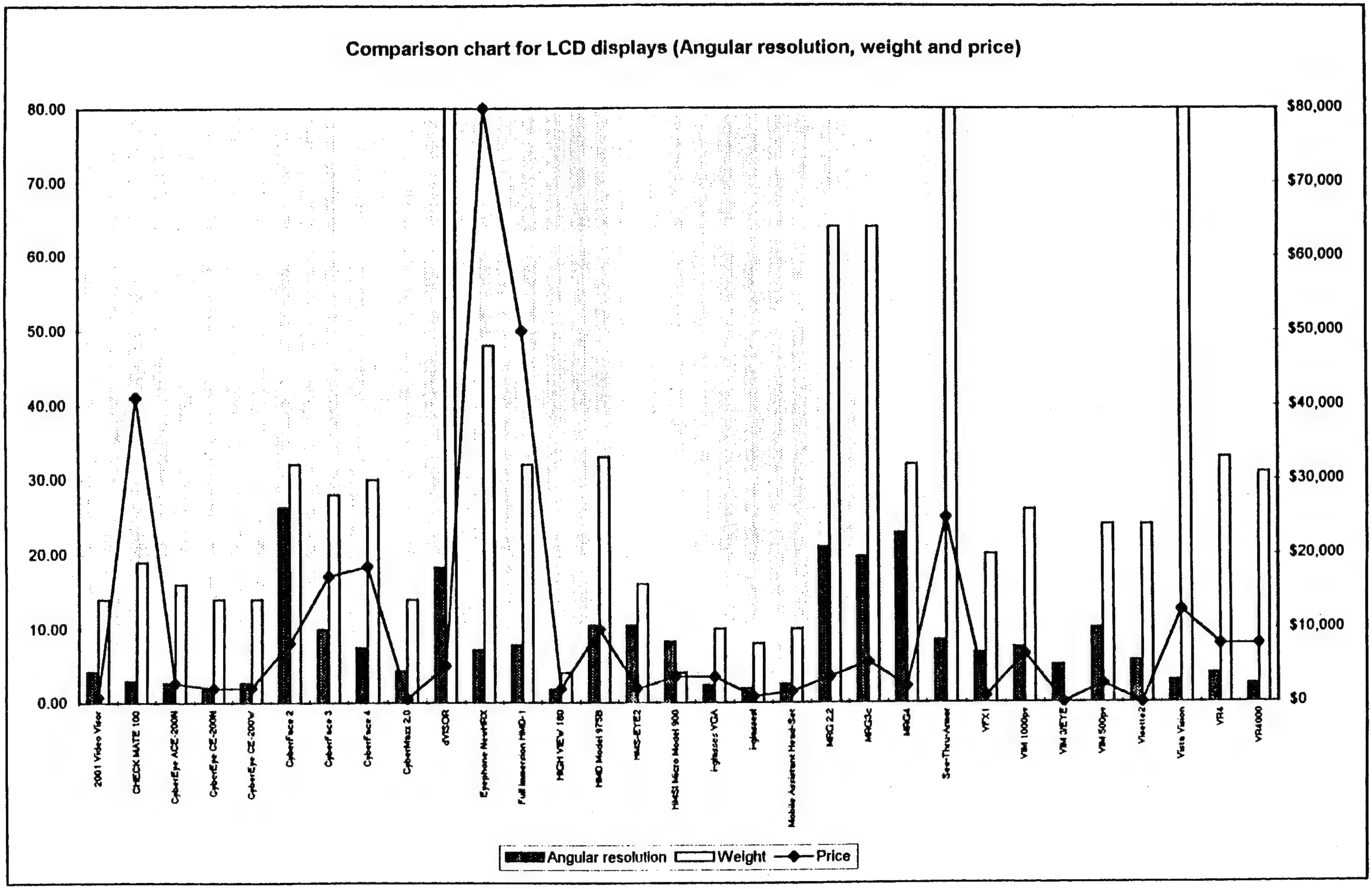
Head Mounted Displays



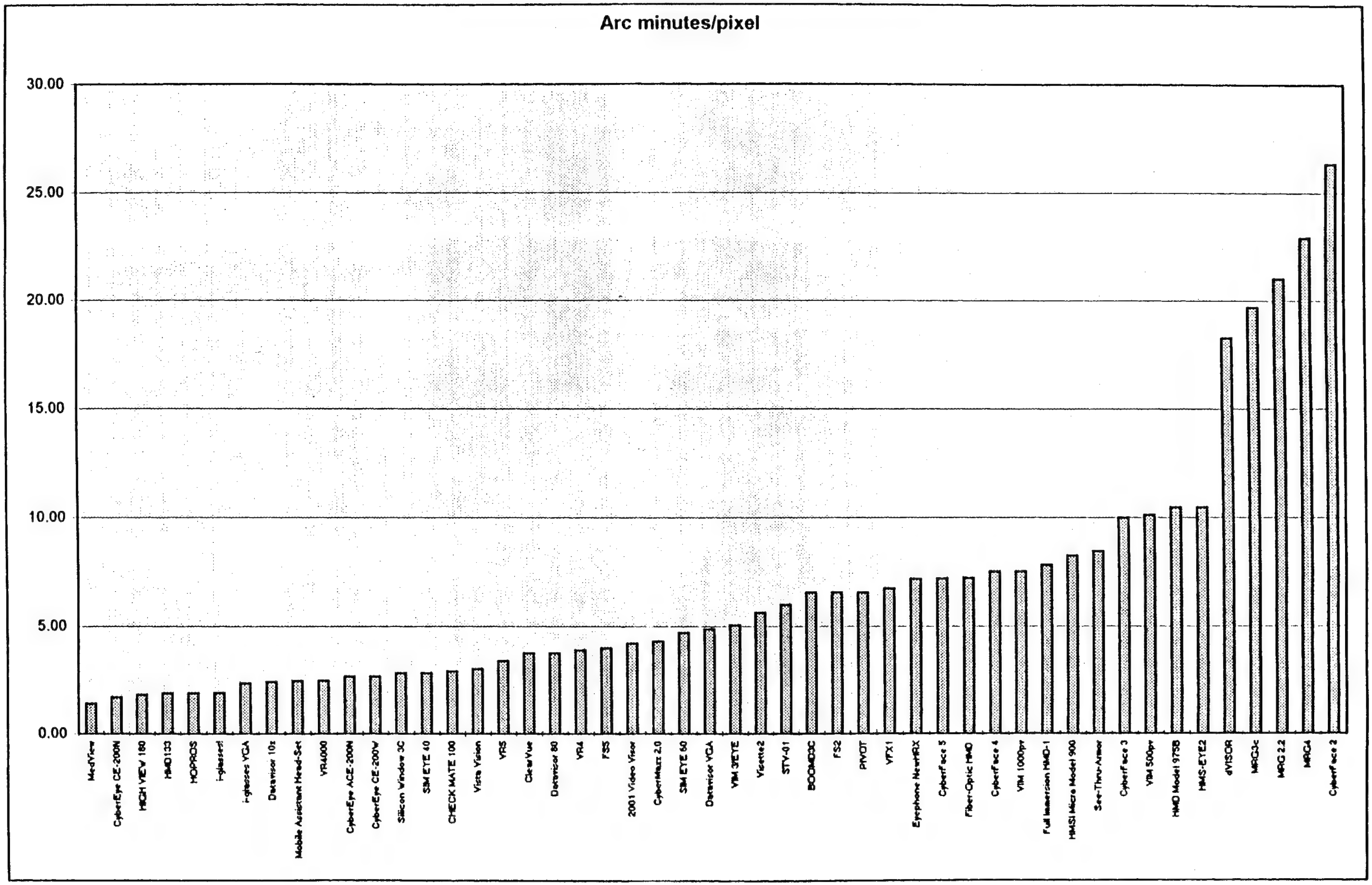
Head Mounted Displays



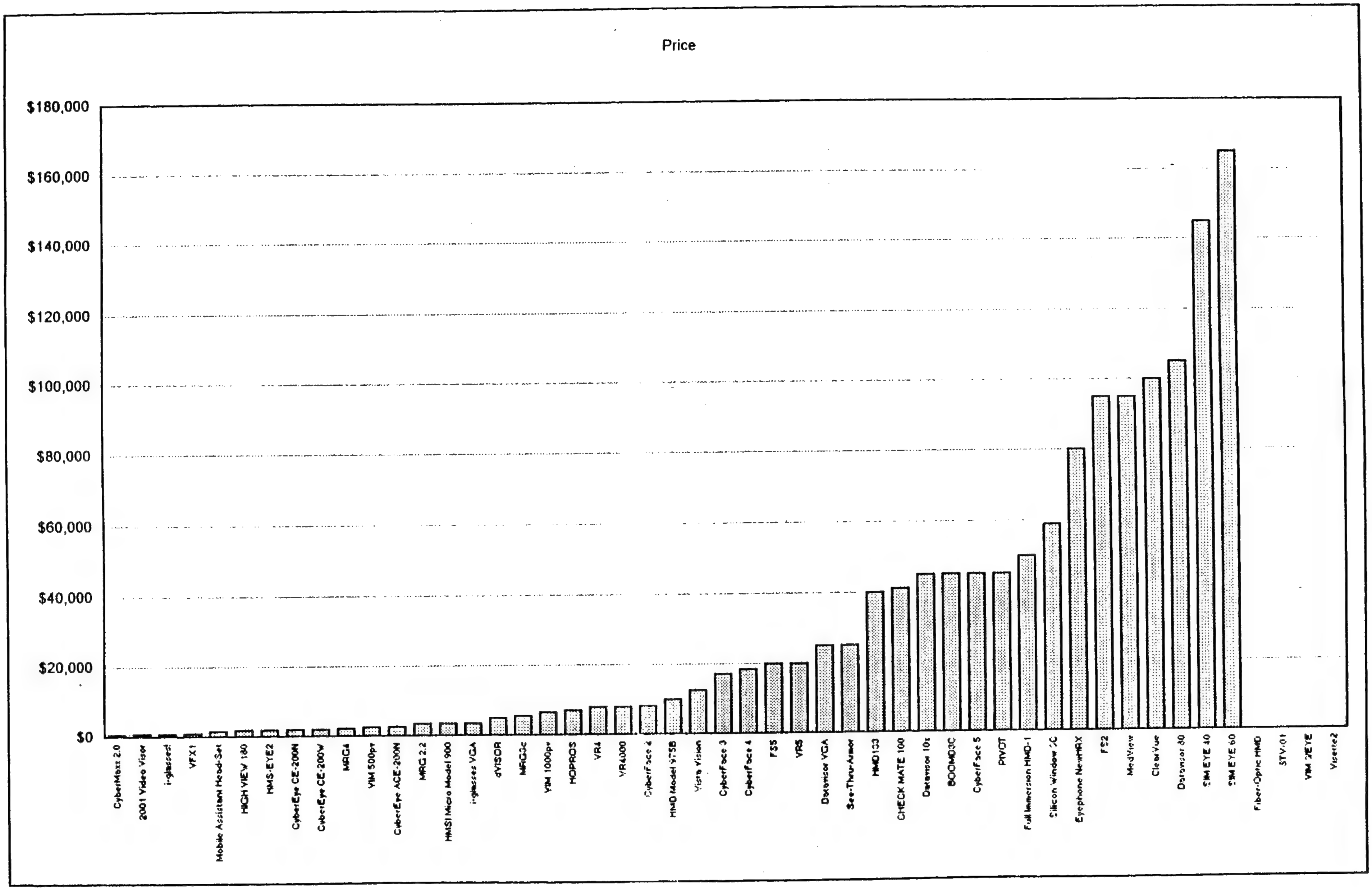
Head Mounted Displays



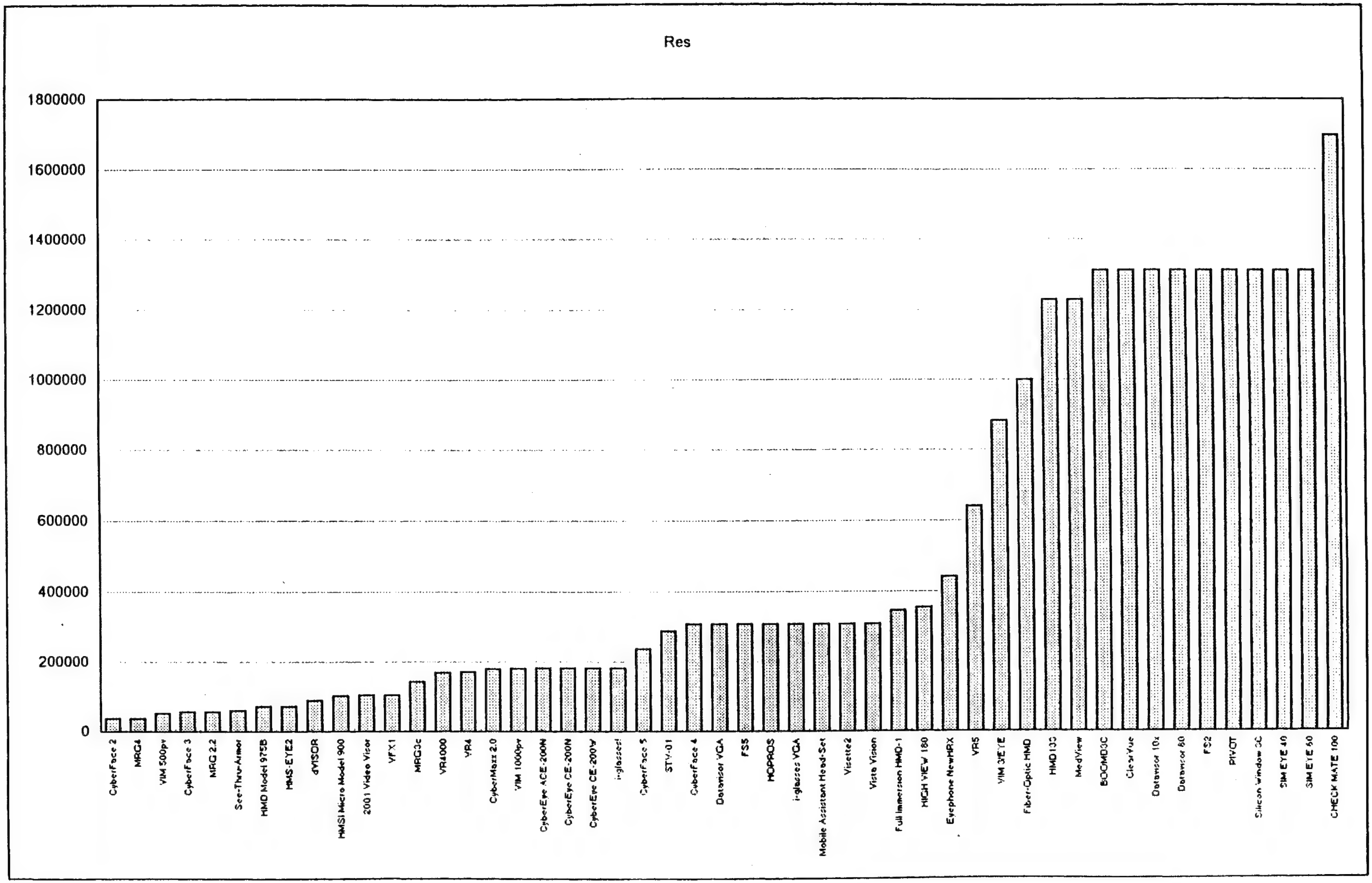
Head Mounted Displays



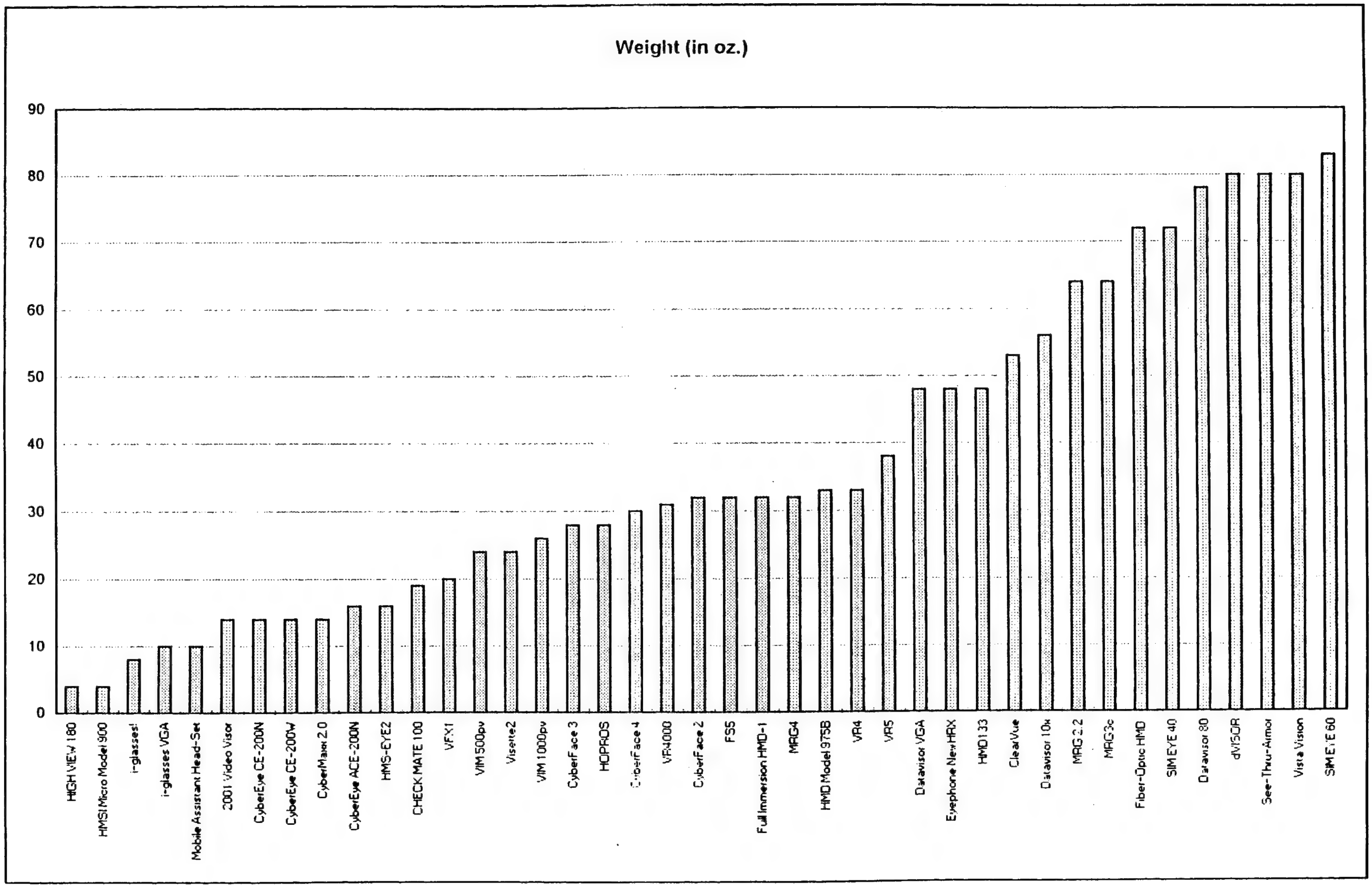
Head Mounted Displays
- Price -



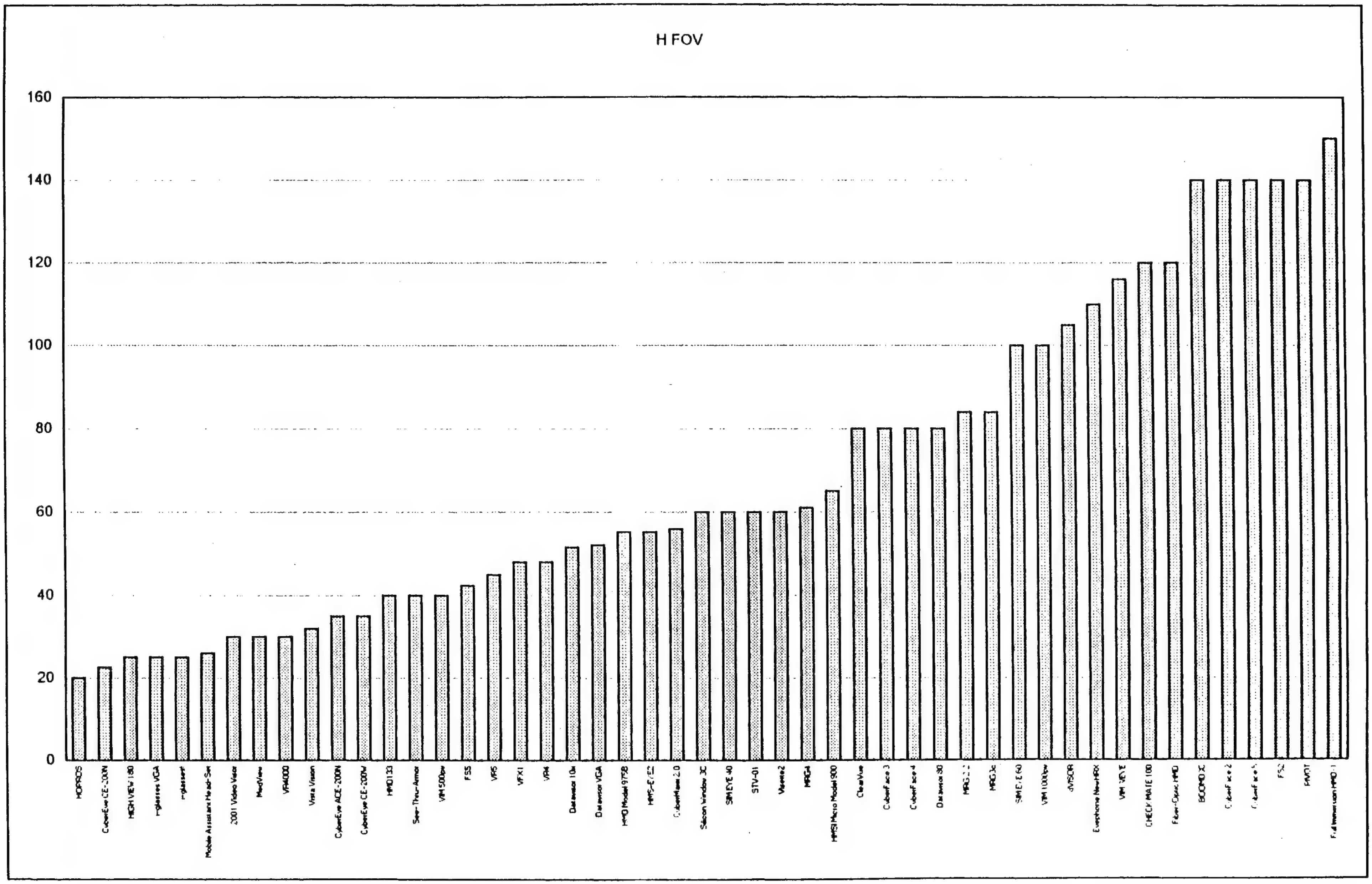
Head Mounted Displays
Resolution (total no. of pixels)



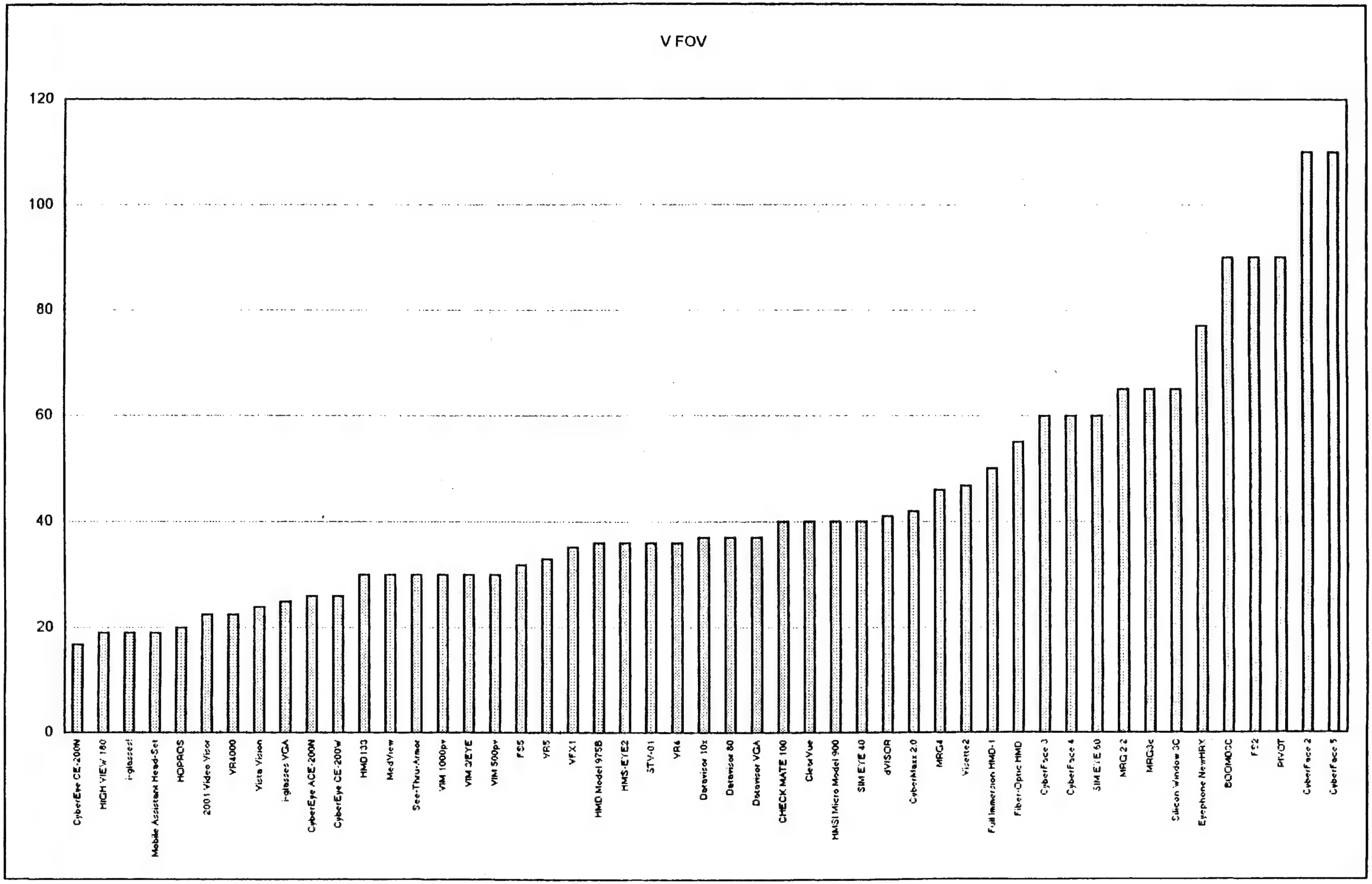
Head Mounted Displays



Head Mounted Displays
- Horizontal Field of View -



Head Mounted Displays
- Vertical Field of View -



Spacial Sound

SPATIAL SOUND

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1. Introduction

In recent years, the increasing ability of low-end graphics workstations to produce quality images at usable frame rates for real-time display has enabled a multitude of commercial and research institutions to begin exploring virtual environments. Some applications are as simple as improving the quality of arcade type games and some are as far reaching as telepresence robotic applications and scientific visualizations. Along with these new and improved visualization tools, a ground swell of interest in three dimensional audio, also referred to as spatial audio, has emerged. In a virtual environment, as you move to the left or right, you expect the view to move accordingly. Similarly, if an event occurs on your left, such as a ball impacting a wall, you expect to hear the sound to your left . The addition of audio cues to a virtual environment dramatically increases the level of immersion for the user.

3D sound, often termed spatial sound, is sound as we hear it in everyday life. Sounds come at us from all directions and distances, and individual sounds can be distinguished by pitch, tone, loudness, and by their location in space. The spatial location of a sound is what gives the sound its three-dimensional aspect.

The constant influx of sound from our environment provides much information of the world around us. Slight echoes and reverberations in the surrounding environment give the brain cues about the direction and distance of objects from us. These cues also relay information about the size of the environment surrounding us. For example, a small room has fewer echoes than one with cathedral ceilings. Additionally, the presence of objects in the environment outside the field of view can be felt by hearing sounds emitted from those objects. In this way, hearing those sounds also serves as a cue to turn to locate the sound source. Finally, information about the material qualities of objects and the environment around us can be gathered through sounds. You can tell, for example, if an object is soft or hard by dropping it on a hard surface and observing the sound it makes. Similarly, you can gain information about the physical qualities of the ground through sound. For example, walking on wet surface yields the squishing sounds made as your feet make contact with the wet surface.

Being able to accurately synthesize such spatial sound would clearly add to the immersiveness of a virtual environment. Sounds are a constant presence in our everyday world and offer rich cues about our environment. Sound localization, however, is a complex human process. Efforts to artificially spatialize sounds must first understand how humans actually hear and localize sounds.

1.1 Background

Humans determine the locality of a sound based on refraction in the vicinity of the head and upper body and the effect of resonances inside the ear [39]. The dominant cues provided by these head and upper body effects are interaural delay time (IDT) [Rayleight07], head shadow [Mills72], pinna and ear canal response [Gardener73], and shoulder echoes [Searle76]. Often referred to as the interaural group delay or interaural time difference, the IDT appear to provide the primary cue for determining the lateral position of a sound [Blauert83]. Simply put , this refers to the delay between a sound reaching the closer ear and the farther one.

"The delay is zero for a source directly ahead of, behind, or above the listener, and roughly 0.63ms for a source to one's left or right . The delay varies as a sinusoid with azimuth but is also dependent on both frequency of the sound and the distance of the source. IDT manifests itself as a phase difference for signals below 1.6kHz and as an envelope delay for higher frequency sound." [Blauert83]

2. Methods to synthesize spatial sound

In order to gain a clear understanding of spatial sound, it is important to distinguish monaural, stereo, and binaural sound from 3D sound.

2.1 Monaural

A monaural sound recording is a recording of a sound with one microphone. No sense of sound positioning is present in monaural sound. Since the stereo sound cards and stereo recorders are so cheap, the mono recordings are almost extinct.

There are two basic ways of making two-channel audio recordings: stereo and binaural.

2.2 Stereo

The most common is stereo. A stereo recording captures differences in intensity and, possibly, differences in phase between points in a sound field [Burg92]. From these differences, the listener can gain a sense of the movement and position of a sound source. However, the perceived position of a sound source is usually along a line between the two playback speakers, and when monitored with headphones, sound sources appear along an axis through the middle of the head. This effect is due to the fact that the microphones used for stereo recording provide a poor model of the way sound really arrives at the ears. Human ears are not several feet apart, they do not have symmetric field patterns, and they are not separated by empty space.

Stereo sound cards are the cheapest and now almost any PC is equipped with a stereo sound card. See the stereo cards tale for prices and specifications.

2.3 Binaural

The other method for two-channel audio recording is binaural. Binaural recordings are intended to be reproduced through headphones, and can give the listener a very realistic sense of sound sources being located in the space outside of the head. Sounds can be in front of, behind, or even above or below the listener. This effect is achieved by using a better model of the human acoustic system, such as a dummy head with microphones embedded in the ears (Plenge, 1974). Because of the better model, the sound waves that arrive at the eardrums during playback are a close approximation of what would have actually arrived at a listener's eardrums during the original performance.

Along with greater realism, binaural sound provides a number of other advantages over plain stereo. It conveys spatial information about each sound source to the listener. Furthermore, when sounds are spatially separated, a listener can easily distinguish different sources, and focus on those sources which are of interest while ignoring others. This is the so-called "cocktail party effect" (Cherry, 1953).

In strict terms, "binaural" and "stereo" mean exactly the same thing—two channels of sound. However, in the music recording field, these terms often carry the different meanings given here.

In synthesizing accurate 3D sound, attempts to model the human acoustic system have taken binaural recordings one step further by recording sounds with tiny probe microphones in the ears of a real person. These recordings are then compared with the original sounds to compute the person's head-related transfer function (HRTF). The HRTF is a linear function that is based on the sound source's position and takes into account many of the cues humans used to localize sounds, as discussed in the previous section. The HRTF is then used to develop pairs of finite impulse response (FIR) filters for specific sound positions;

each sound position requires two filters, one for the left ear, and one for the right. Thus, to place a sound at a certain position in virtual space, the set of FIR filters that correspond to the position is applied to the incoming sound, yielding spatial sound [39].

The computations involved in convolving the sound signal from a particular point in space are demanding. Refer to [BURGESS92] for details on these sound computations. The point to recognize is that the computations are so demanding that they currently cannot be performed in real-time without special hardware. To meet this need, Crystal River Engineering has implemented these convolving operations on a digital signal processing chip called the Convolvotron. The professional systems using this chip (made by Crystal River Engineering) are still very expensive but the trend seems to lead to cheaper 3D sound systems in the next future. See the "3D Sound Convolvers" table for price and specifications.

2.4 3D Sound Rendering

Sound rendering is a technique of generating a synchronized soundtrack for animations. This method for 3D sound synthesis creates a sound world by attaching a characteristic sound to each object in the scene. Sound sources can come from sampling or artificial synthesis. The sound rendering technique functions in two distinct passes. The first pass calculates the propagation paths from every object in the space to each microphone; this data is then used to calculate the geometric transformations of the sound sources as they correlate to the acoustic environment. The transformations are made up of two parameters, delay and attenuation. In the second pass, the sound objects are instantiated and then modulated and summed to generate the final sound track. Synchronization is inherent in the use of convolutions that correspond to an objects position with respect to the listener [TAKALA92].

3. Problems with Spatial Sound

A classic problem with spatial sound is an inability of listeners to tell whether sound sources are in front of or behind them. This problem is not necessarily due to some failing of the spatial sound system, because front-back confusion can occur with real sound sources as well.

Another common shortcoming is lack of externalization. As a result, sound may appear to emanate from points inside the head. Externalization is lost when signals reaching the ears are not adequately consistent with those that would be produced by external sources (Plenge, 1974).

Localization is the sense that a sound is coming from a particular direction, instead of just vaguely from one side or the other.

A minimum requirement for any useful spatial sound system is a monotonically increasing relationship between perceived position and target position. Position update rates should be high enough to give an illusion of continuous movement. An update rate of 10Hz has been found to be adequate for rotational speeds of up to 180 degrees/second [1]

Another important requirement for spatial audio to be useful in an interface is a control protocol between the interface software and the spatialization system. It is already known that this protocol must meet several requirements:

- It should provide means for the interface software to present a script specifying the choreography of multiple sound sources.
- It should provide immediate update capabilities so that sounds (or scripts) may be initiated, interrupted, or changed in real time.
- Available methods for host-to-DSP communication vary widely. The protocol should assume a simple communication model (a lowest common denominator) to be portable to a variety of systems.
- It should allow for the integration of acoustic event caches.
- It should allow for the integration of head-tracking devices.
- It should allow for the integration of suitable data compression schemes to reduce I/O bandwidth.

Problems in Headphone Reproduction:
1) Acoustical coupling: the headphone response measured at the eardrum is different for each listener.
2) Many varieties of headphones: they differ in as many disastrous ways as do loudspeakers.
3) Externalized frontal imagery is quite rare

Attempts to Address Problems in Headphone Reproduction [23]:
1) Use interactive head- tracking: the listeners voluntary head motions provide binaural cues that can disambiguate front/rear and above/below directions.
2) Coordinate with visuals.

Problems in Loudspeaker Reproduction:
1) Loudspeaker response: should be flat in magnitude and linear in phase.
2) Room acoustics: environmental reverberation adds to the present in the recording.
3) Transmission path: differs for each listeners seating location - especially bad toward the sides near the front of the space.
4) Crosstalk: both ears receive the signals from both loudspeakers.

At tempts to Address Problems in Loudspeaker Reproduction [23]:
1) Loudspeaker response: Choose well and equalize as best as possible.
2) Room acoustics: Design for reflection- free zones (RFZs) , or retrofit existing spaces through the use of acoustical absorption and diffusion.
3) Transmission path: Process the stereo signal to spread the sweet spot.
4) Crosstalk: Apply transaural processing to cancel the unwanted signals. [Martens92]

4. Applications of 3D sound

Sound has many potential applications in the areas of virtual reality and telepresence, but hardware costs have made most of these applications impractical. Recently, however, single-chip digital signal processors have made real-time spatial audio an affordable possibility for many workstations.

As previously discussed, spatial sound could help increase the sense of presence in virtual environments by relaying information about the environment and the objects within it. Such environmental awareness could be very beneficial in increasing the user's orientation in virtual environments.

- Sound can also be used as a substitute for other sensory feedback in virtual environments. For example, pushing a virtual button is a task detected by wired glove. Without haptic feedback, however, users have had difficulties knowing when the button was successfully activated [BEGAULT92]. Sound cues have been used to alleviate this problem; hearing the sound of the button being pushed gave users the immediate feedback needed to know that their actions were indeed successful.

- Similarly, sounds can be used to compensate for sensory impairments of specific users. The Mercator project, for example, is researching the use of sound as alternative, nonvisual interface to X Window System applications for visually impaired software developers [BURGESS92]. The goal of the project is to map the behaviors of window-based applications into an auditory space; spatial sound is being used heavily to relay information about the organization of objects on the user's screen.

- Using sound as an additional input channel for computer-human interaction has begun to be researched [SMITH93], but much more human factors work needs to be done before sound can be accurately utilized for data representation in user interfaces. The auditory channel is currently underutilized in user interfaces, and the potential exists to increase the bandwidth of information relayed to users by using sound in addition to visual and other sensory outputs to relay information to users.

3D sound is a new technology that is early in the stages of development and understanding. More potential applications will continue to unfold as our understanding of spatial hearing and ways to artificially recreate it continue to evolve [39].

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3D Sound Convolvers

Company	Model	Input	Price	Comments
Crystal River Engineering	Convolvotron	4 channels	$15,000	
Crystal River Engineering	Beachtron	2 channels	$1,495	PC board, synthesizer
Crystal River Engineering	Alphatron	2 channels	$495	PC board
Crystal River Engineering	Acoustetron II	8 channels	$11,995	stand-alone system
Focal Point 3D Audio	Focal Point	2 channels	$1,500	Mac or PC board, synthesizer
Visual Synthesis	Audio Architect	2 channels	$500	development system for SGI, Sun, DEC
Visual Synthesis	Audio Image Sonic Architect	2 channels	$1,500	development system for SGI, Sun, DEC, absorbtion and reflection models
Visual Synthesis	Audio Image Sound Cube	2-8 channels	$8,000	real-time sound manipulation

Company	Model	Chipset	I ch.	O44	O19	MIDI synth.	Price	Comments
Advanced Gravis Computer Technologies	Gravis Ultrasound	Gravis GF1	2	14	32	Wavetable	150	
Advanced Gravis Computer Technologies	Gravis Ultrasound Max	Gravis GF1	2	14	32	Wavetable	200	Crystal CODEC
Turtle Beach Systems	Multisound Classic	Proteus 1/XR	2	2	2	Wavetable	350	Motorola 56001 DSP
Turtle Beach Systems	Multisound Monterey	ICS Wavefront 2115	2	2	2	Wavetable	320	Motorola 56001 DSP
Creative Labs	Sound Blaster 2.0	Creative	1	1	1	FM	50	Yamaha OPL-2
Creative Labs	Sound Blaster Pro	Creative	2	2	2	FM	75	Yamaha OPL-3
Creative Labs	Sound Blaster 16	Creative	2	2	2	FM	100	Yamaha OPL-3
Creative Labs	Sound Blaster AWE-32	EMU8000	2	2	2	Wavetable	300	Yamaha OPL-3

Legend:

I ch. = Input channels (2=stereo, 1=mono)
O44 = Output channels at 44kHz
O19 = Output channles at 19kHz
MIDI synth. = MIDI synthesis

Heat Sensors and Actuator Transducers Requirements for Virtual Environment Users - Physiological Considerations -

Heat Sensors and Actuator Transducers Requirements
for Virtual Environment User
- *Physiological considerations* -

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General Concept of Thermoreceptors

The concept of thermoreceptors is based originally on human sensory physiology, in particular on the fact that thermal sensations can be elicited from localized sensory spots in the skin [3]. Detailed investigations have revealed a differentiation of "warm" and "cold" spots, that is, local areas responding only with warm or cold sensations. It seems thus justified to speak of specific thermoreceptors in the sense that temperature sensations are correlated with localized neural structures. This type of specificity could be called *"sensory specificity"*.

On one hand, cutaneous thermoreceptors are the source of conscious temperature information but on the other hand they are perhaps even more important in connection with behavioral and thermoregulatory responses [3]. Thus the physiology of thermoreceptors implies various approaches, namely:

1) temperature sensations,
2) afferent impulses from units responding to thermal stimulation,
3) behavioral responses to thermal stimulation,
4) thermoregulatory reflexes.

Since the most important and less studied for heat (or cold) simulation in a virtual environment are the thermal sensations we will try to explain several factor involved in this sensory process.

Structure of temperature sensation

It is relatively easy to discriminate the phenomenal qualities of warm and cold from the manifold of cutaneous sensations. Both qualities form a sensory continuum of various intensities: "indifferent" - "lukewarm" - "warm" - "hot" - "heat pain" on the warm side and similar intensity classification on the cold side.
Whether the sensation of "heat" is only a more intense warm sensation or a mixture of various qualities is not quite clear. According to ALRUTZ heat is a combination of warmth and "paradoxical" cold. Another author (Iggo, 1959) suggests that perhaps "heat" might be a quality of its own, its neurophysiological correlate being the activity of

particular "heat" fibers exited by high-temperatures. There are many theories and studies about the difference between "heat" and "warm" sensations and it seems that until today there is no unanimity among scientists if these two sensations are the same or not. For now, we will suppose that "heat" and "warm" sensations are different just in a quantitative manner: "heat" is when "warm" begins to be painful.

Another important fact is that the experience of thermal comfort and discomfort when larger areas of the body are exposed to various temperatures is not only due to the function of cutaneous thermoreceptors but reflects an integrated state of thermoregulatory system.

Cold and Warm Spots

Since the discovery by Blix (1882) of sensory spots from which adequate or electrical stimuli elicited cold and warm sensations, respectively, numerous authors have described the distribution of cold and warm spots in the skin of man. In general, cold spots seems to be distributed more densely than warm spots (table 1). Investigations on the topography of warm spots in the external skin of human subjects seems to be pretty sparse in the last years. The most cited studies are those made by Rein (1925), Skramlik (1937) and Hensel (1952).

	Cold spots[a]	Warm spots[b]
Forehead	5.5-8	
Nose	8	1
Lips	16-19	
Other parts of face	8.5-9	1.7
Chest	9-10.2	0.3
Abdomen	8-12.5	
Back	7.8	
Upper arm	5-6.5	
Forearm	6-7.5	0.3-0.4
Back of hand	7.4	0.5
Palm of hand	1-5	0.4
Finger dorsal	7-9	1.7
Finger volar	2-4	1.6
Thigh	4.5-5.2	0.4
Calf	4.3-5.7	
Back of foot	5.6	
Sole of foot	3.4	

Table 1. Number of cold and warm spots per square centimeter in human skin ([a]From STRUGHOLD and PORZ, [b]From REIN)

Thermal Sensation and Temperature

By means of fine thermocouples it has been possible to measure directly the intracutaneous temperature field under stationary and non-stationary conditions. When a cutaneous area, such as hand or foot, is adapted to a constant temperature of 25°C, linear temperature rises will cause a sequence of sensations from "cool" to "warm" (fig. 1). After having reached a constant temperature level, the intensity of sensation decreases considerably. On linear cooling with a similar slope, the cold sensation starts at the same temperature at which warm sensation occurs when the temperature is rising.

At high and low temperatures, steady sensations occur at constant skin temperature but, the limits for this steady sensations are about 24 and 35°C. Other studies shows that these limits are highly dependent on the stimulus area, for example Hensel (1950) found that for a 20cm^2 stimulus area the limit for steady cold sensations was 20°C and for steady warm sensations 40°C.

Stimulus Area

Numerous investigations have revealed a considerable influence of stimulus area on the thresholds and intensities of temperature sensation. Fig. 2 shows the warm thresholds at uniform rates of linear temperature increases as a function of stimulus area from 1 to 1000 cm^2.

It should be mentioned here that the results from stimulus areas less than 1 cm^2 are difficult to interpret, since the factor of three-dimensional heat flow becomes decisive at small areas.

In connection with the biological importance of thermoreception in man, the results obtained by stimulation of large cutaneous areas or of the hole body surface are of particular interest. Marechaux and Schaefer have measured the warm thresholds when the whole body temperature rises from 0.001 to 0.01°C/sec. Under these conditions even extremely slow rates of changes of 0.001°C/sec led to warm sensations at skin temperatures of 35°C. This corresponds well with the observation that thermal comfort is restricted to a relatively narrow range of integral skin temperature, approximately from 32 to 34°C.

The Adequate Stimulus

As a result of previously described findings, the threshold and intensity of warm sensations are dependent:

- on the absolute temperature of the skin
- on the rate of change and
- on the stimulus area (size and localization).

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